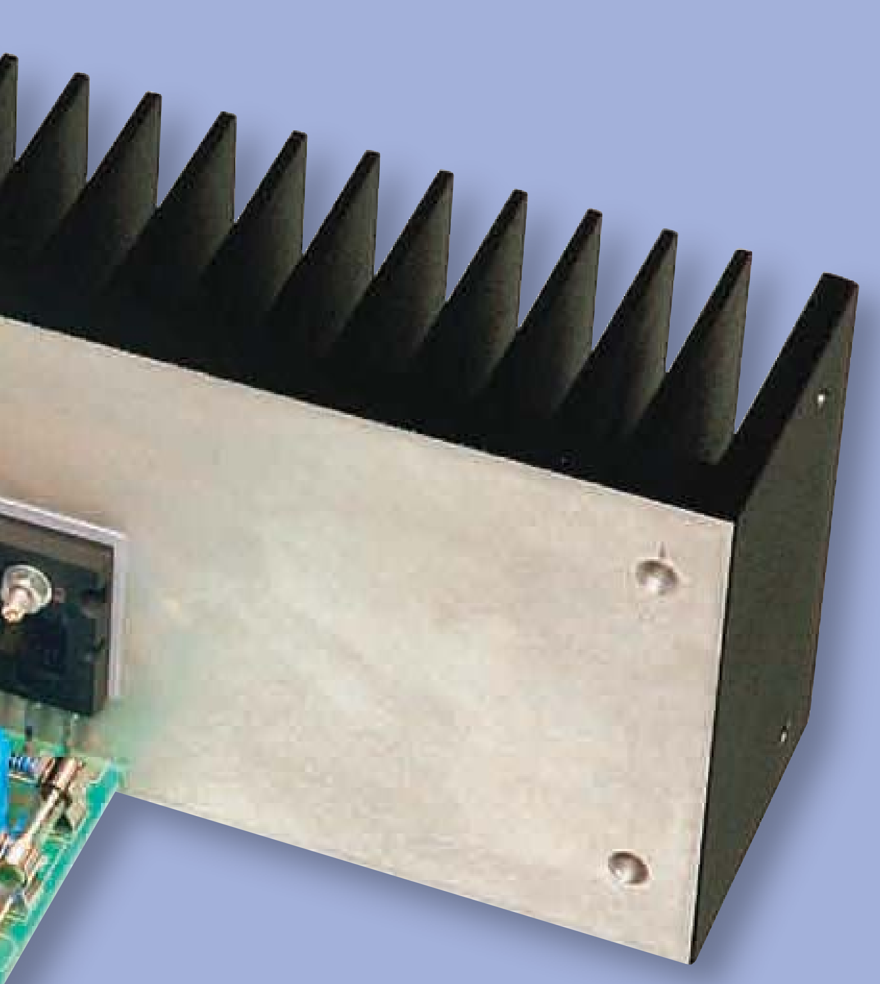
20W Class-A Amplifier Module

PART.1: By LEO SIMPSON & PETER SMITH

This new 20W class-A power amplifier module features ultra-low distortion levels, very low noise levels and a greatly simplified power supply, which improves overall efficiency. Since it runs in pure class-A mode, there is no crossover distortion at all.



The MJL21193 and MJL21194 output transistors are spaced well apart and bolted to a large heatsink. The heatsink may look big, but it has to be that size to safely dissipate around 50W continuously. This view shows the lefthand power amplifier module. The righthand module is laid out almost as a mirror image.

THIS high-performance class-A amplifier has been a long time coming. Readers have been hankering for a more powerful, high-quality class-A amp for sometime now, but until recently, we have resisted because we knew that increasing the power output would bring a proportional increase in overall power consumption.

This is the great drawback of any class-A design. While they are beautifully distortion-free, they dissipate the same high power whether they are delivering a milliwatt, one watt or full power. That's quite a lot of power dissipation for not very much audio output.

So, how could we increase the power output while staying within certain parameters – ie, large single-sided heatsinks and a 160VA toroidal power transformer? The answer was not simple, but essentially involved analysing the weaknesses of our planned circuit as we progressed to see if we could make worthwhile improvements.

The result is, we made quite a few minor modifications to our original amplifier circuit, which, together, adds up to an overall improvement in the circuit's performance. It also enabled us to dispense with a regulated power supply. This makes the overall circuit more efficient, and means that the amplifier can now use some of the power that would have been previously wasted in the regulated supply. This also reduces component cost and actually helps reduce distortion in an already exceptional design.

Some of the changes in the design are based on ideas and circuits published by the noted audio designer Douglas Self and outlined in a number of his books.

Redesigned PC board

We completely re-designed the PC board so that the two power output transistors are spread much further apart. Instead of concentrating the heat in the centre of the heatsink, it spreads the heat over a wider area and makes more efficient use of the available heatsink area. In fact, while the new amplifier module can deliver up to 25W (instead of the original 15W), the heatsink temperature remains about the same – ie, about 30°C above ambient.

We must stipulate that even though the amplifier can deliver up to 25W at the onset of clipping, it only provides pure class-A operation up to 20W. Beyond this, it is operating class AB – still with very low distortion – but not genuine class-A.

We made this compromise to reduce the temperature rise on the heatsinks. With sufficient quiescent current to ensure class-A operation up to 25W, the heatsinks simply became too hot.

In fact, the circuit is actually slightly more 'voltage-efficient' than the old one, so that the available output voltage from the balanced supply rails is greater than before. We will see just how these improvements have come about as we go through the circuit description.

Performance

We will present the complete circuit description and mention the differences with the older design where appropriate. But first, let's talk about performance.

The distortion of this new design is amazingly low. Fig.1 shows the total harmonic distortion at 1kHz for power levels from 100mW up to clipping, which occurs in excess of 25W. Note

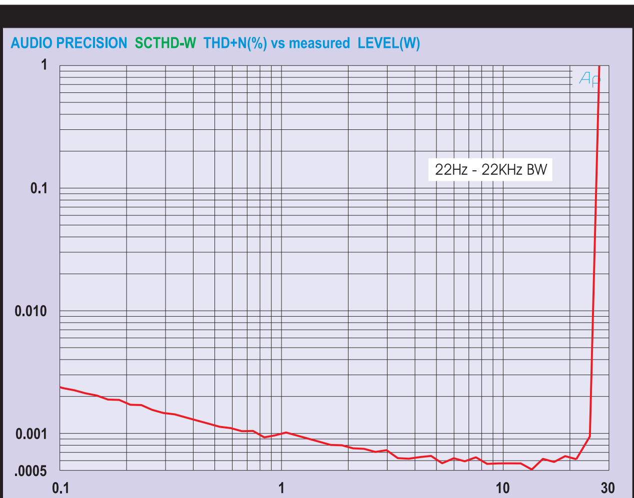


Fig.1: this graph plots the total harmonic distortion (THD) at 1kHz from 100mW to just over 25W.

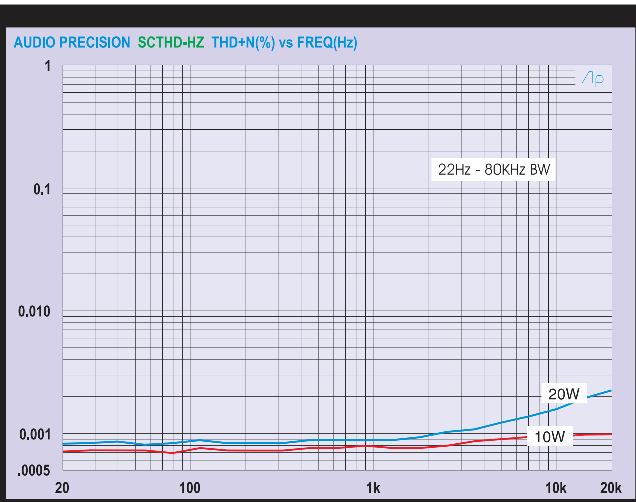


Fig.2: the distortion versus frequency at 10W and 20W into an 8Ω load (measurement bandwidth 22Hz to 80kHz).

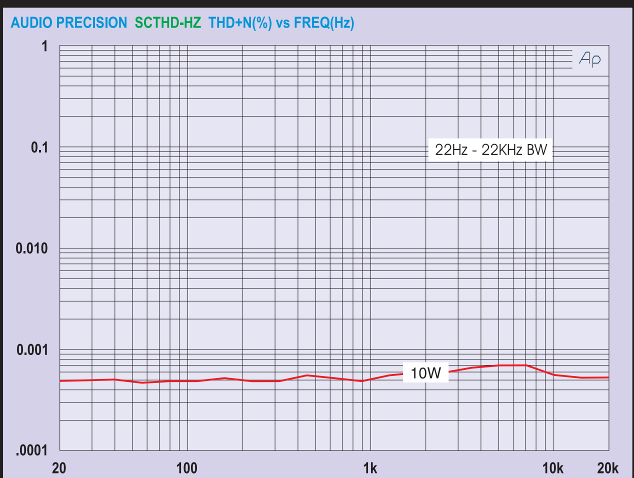


Fig.3: distortion vs frequency at 10W from 20Hz to 20kHz (measurement bandwidth 22Hz to 22kHz).

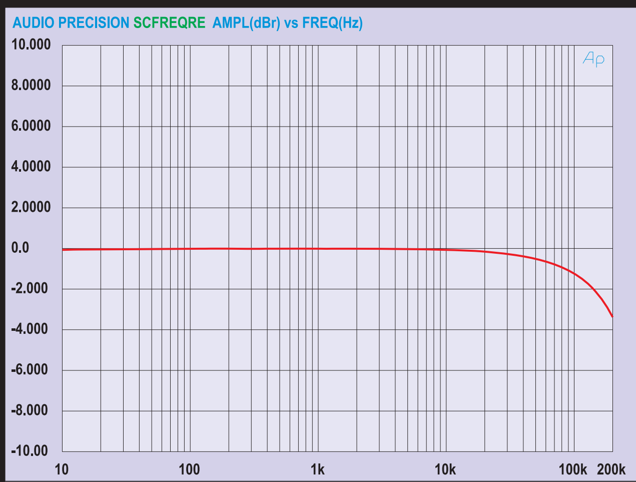


Fig.4: the frequency response is 'ruler' flat over the audible frequency range, with –3dB points at 1.5Hz and 190kHz.

that the distortion for power levels between say 5W and 20W is far below 0.001% and is typically less than 0.0006% at around 10W.

Similarly, Fig.2 shows the distortion versus frequency for power levels of 10W and 20W into an 8Ω load, using a measurement bandwidth of 22Hz to 80kHz. This is a far more stringent test, as the distortion for any amplifier, even quite good designs, usually rises quite markedly at high powers for frequencies above 5kHz. But for this design, at 10W, the distortion at 20kHz is only marginally above that at 1kHz. At 20W, the new design has about half the distortion of the original at 15W, and that is right across the spectrum, not just at one frequency!

Fig.3 is included largely as a matter of academic interest and is taken for a power output of 10W for frequencies from 20Hz to 20kHz, but with a bandwidth of 22Hz to 22kHz. Note that this means that harmonics above 22kHz will be ignored and therefore the distortion for signal frequencies above 10kHz will be artificially attenuated.

Frequency response is 'ruler' flat, as shown in Fig.4. It is –1dB at 90Hz and –3dB at 1.5Hz and 190kHz. This is a much wider frequency response than the original circuit and comes about because we have used much gentler filtering at the input of the amplifier. We will describe the reasoning behind this later in the article.

Residual noise measurements have also improved. Unweighted signal-to-noise ratio, with respect to 20W into 8Ω, is –115dB, while the A-weighted figure is –118dB.

Even though those noise figures are highly creditable, they are not low enough to enable us to accurately measure the distortion at low power (ie, below 5W). This is because the residual noise becomes a significant part of the measurement and largely masks the actual distortion. We hope to feature some equivalent scope plots next month.

For the moment, we can unequivocally state that this new class-A amplifier module is one of the lowest distortion designs ever produced, anywhere!

Circuit concept

The full circuit diagram of the 20W Class-A Amplifier module is shown in Fig.5. While the general configuration is similar to that used in our first circuit, very few

Parts List – 20W Class-A Amplifier Module

1 PC board, code 687 ('left') or 688 ('right'), available from the *EPE PCB Service*, size 146mm × 80mm
2 Micro-U TO-220 finned heatsinks (20° C/W)
3 TO-126 heatsink pads
2 TO-3P heatsink pads (Farnell 936-753 recommended, see text in Part 2)
1 diecast heatsink, 300 × 75 × 49mm (W × H × D) (Altronics H-0545)
1 PC-mount phono socket (CON1)
2 M3 × 10mm tapped spacers
2 M3 × 6mm pan head screws
2 M3 × 10mm pan head screw
2 M3 × 20mm pan head screws
6 M3 flat washers
4 M3 nuts
5 M4 × 10mm screws
5 M4 flat washers
5 M4 shakeproof washers
5 M4 nuts
5 6.3mm single-ended chassis-mount spade lugs
4 M205 fuse clips (F1 and F2)
2 3A M205 slow-blow fuses
1 11.8mm or 13.8mm ID bobbin
1 2m length of 1mm-diameter enamelled copper wire
0.7mm diameter tinned copper wire for links
1 1kΩ 25-turn trimpot VR1

Semiconductors
2 2SA970 low-noise *PNP* transistors (Q1 and Q2) (available from **www.futurlec.com**)
4 BC546 *NPN* transistors (Q3, Q4, Q8 and Q9)
3 BC556 *PNP* transistors (Q5 to Q7)
2 BD139 *NPN* transistors (Q10 and Q11) (Farnell 955-6052)
1 BD140 *PNP* transistor (Q13) (Farnell 955-6060)
1 MJL21193 *PNP* transistor (Q12) (Jaycar ZT-2227, Farnell 955-5781)
1 MJL21194 *NPN* transistor (Q14) (Jaycar ZT-2228, Farnell 955-5790)
2 1N4148 signal diodes (D1, D2)

Capacitors
1 1000µF 35V PC electrolytic
2 470µF 35V PC electrolytic
4 47µF 25V PC electrolytic
1 220µF 25V PC electrolytic
1 820pF 50V ceramic disc
1 100pF 50V NPO ceramic disc (Jaycar RC-5324)
4 100nF metallised polyester (MKT)
1 150nF 250V AC metallised polyester or polypropylene (Farnell 121-5452)

Resistors (0.25W, 1%)

1 1MΩ	1 510Ω
4 10kΩ	1 270Ω
3 2.2kΩ	8 100Ω
1 1kΩ	3 68Ω
1 680Ω	1 16Ω

1 6.8Ω 1W 5%
1 10Ω 1W 5%
2 0.1Ω 5W 5% wirewound
R1 See text and Part 2
2 1.5Ω 5W 5% wirewound (for testing)

Power Supply

1 PC board, code 689, size 134mm × 63mm
1 16V+16V 160VA magnetically shielded toroidal transformer (see text in Pt.2).
4 M3 × 10mm tapped spacers
4 M3 × 6mm pan head screws
6 M4 × 10mm pan head screws
6 M4 flat washers
6 M4 shakeproof washers
6 M4 nuts
3 6.3mm single-ended chassis-mount spade lugs
3 6.3mm double-ended 45° or 90° chassis-mount spade lugs
Extra heavy-duty hook-up wire and spade crimp lugs for low-voltage wiring
Mains connection hardware to suit installation

Semiconductors
1 KBPC3504 400V 35A bridge rectifier (BR1)
2 3mm red LEDs

Capacitors
6 10,000µF 35V or 50V snap-in PC-mount electrolytics (max. 30mm diameter) (Farnell 945-2869)
2 100nF metallised polyester (MKT)

Resistors
2 2.2kΩ 1W 5%

Transistor quality

To ensure published performance, the MJL21193 and MJL21194 power transistors must be On Semiconductor branded parts, while the 2SA970 low-noise devices must be from Toshiba. Be particularly wary of counterfeit parts.

We recommend that all other transistors be from reputable manufacturers, such as Philips (NXP Semiconductors), On Semiconductor and ST Microelectronics. This applies particularly to the BD139 and BD140 output drivers.

component values are the same. Some of the transistors have been changed, a cascode stage has been omitted, the biasing arrangements for the constant current sources (Q5, Q6 and Q7) have been significantly changed and the impedance of the input and feedback networks has been substantially reduced.

These changes were made to improve the residual noise, the power supply rejection ratio (PSRR) and the voltage efficiency of the amplifier.

In fact, the only stages which are largely unchanged are the V_{be} amplifier (Q10) and the complementary-feedback pair (CFP) power output stage. So let's go through the circuit.

Circuit details

The input signal is coupled via a 47µF 25V electrolytic capacitor and a 100Ω resistor (R2) to the base (B) of transistor Q1, one of an input differential pair (Q1 and Q2) using Toshiba 2SA970 *PNP* low-noise transistors. The 100Ω input resistor (R2) and the 820pF capacitor (C1) constitute a low-pass filter, with a –6dB/octave roll-off above 190kHz.

This is a much lower impedance network than our previous circuit, in order to provide the lowest impedance for the signal source. In fact, a simple 20kΩ volume control, will also degrade the amplifier's noise performance and, for that reason, we will be presenting an active volume control circuit in a future issue.

Performance: Class-A Amplifier Module

Output power: 20W into 8Ω (pure class-A); see text
Frequency response: 0dB down at 20Hz; ~0.2dB down at 20kHz
–3dB @ 1.5Hz and 190kHz (Fig.4)
Input sensitivity: 625mV RMS (for full power into 8Ω)
Input impedance: ~10kΩ
Rated harmonic distortion: <0.002% from 20Hz to 20kHz, typically 0.0006% (Fig.2)
Signal-to-noise ratio: –115dB unweighted, –118dB A-weighted (with respect to 20W into 8Ω, 22Hz to 22kHz bandwidth)
Damping factor: 180 at 1kHz
Stability: unconditional

Both the bias resistor for Q1 and the series feedback resistor to the base of Q2 are set at 10kΩ to minimise source impedance and thereby, Johnson noise.

The gain of the amplifier is set by the ratio of the 10kΩ and 510Ω feedback resistors to a value of 20.6, while the low-frequency roll-off (–3dB) of the gain is set by the 220µF capacitor to 1.4Hz.

Side-effects

Readers may wonder why we used such large electrolytic capacitors in the input and feedback networks. The answer is that we are acting to eliminate any effects of capacitor distortion in the audio pass-band.

Readers might also wonder why we have not used non-polarised (NP) electrolytics for these functions, since they are normally preferable where the capacitor operating voltage is extremely low. The answer is that NP electrolytics could have been used, but they have much greater bulk and we wanted to minimise any extraneous signal pickup due to physically larger capacitors.

That is one of the unwanted side-effects of a much wider frequency response – the amplifier is more prone to EMI (interferance) and, in the extreme case, to supersonic oscillation if the wiring details are not duplicated exactly.

Diodes D1 and D2 are included across the 220µF capacitor as insurance against possible damage if the amplifier suffers a fault which pegs the output to the –22V rail. In this circumstance, the loudspeakers would be protected against damage by a loudspeaker protection module (to be published in a coming month) but the 220µF capacitor would be left to suffer the reverse current.

We have used two diodes here instead of one, to ensure that there is no distortion due to the non-linear effects of a single diode junction at the maximum feedback signal level of about 1V peak.

Voltage gain

Most of the voltage gain of the amplifier is provided by transistor Q9, which is fed via emitter follower Q8 from the collector (C) of Q1. The emitter follower is used to buffer the collector of Q1 to minimise non-linearity. Q9 is operated without an emitter resistor to maximise gain and output voltage swing.

The collector loads for Q1 and Q2 are provided by current mirror transistors Q3 and Q4. Similarly, the collector load for Q9 is provided by a constant current load comprising transistors Q6 and Q7. Interestingly, the base bias voltage for constant current source Q5 is also set by Q6. Q5 is the constant current 'tail' for the input differential pair and it sets the collector current through these transistors.

Power supply rejection ratio

The reason for the rather complicated bias network for Q5, Q6 and Q7 is to produce a major improvement in the power supply rejection ratio (PSRR) of the amplifier. Similarly, the PSRR is improved by the bypass filter network, consisting of the 10Ω 1W resistor and a 1000µF 35V capacitor in the negative supply rail.

Why is PSRR so important? Because this amplifier runs in class-A, it pulls a constant current in excess of 1A (actually 1.12A) from the positive and negative supply rails. This is a great deal higher than the typical quiescent current of a class-B amplifier, which is typically around 20 to 30mA.

The result of this is that the 100Hz ripple superimposed on the supply lines is about 500mV peak-to-peak, when two modules are connected. Hence, we need a PSRR that is much higher than for a typical class-B amplifier.

Output drivers

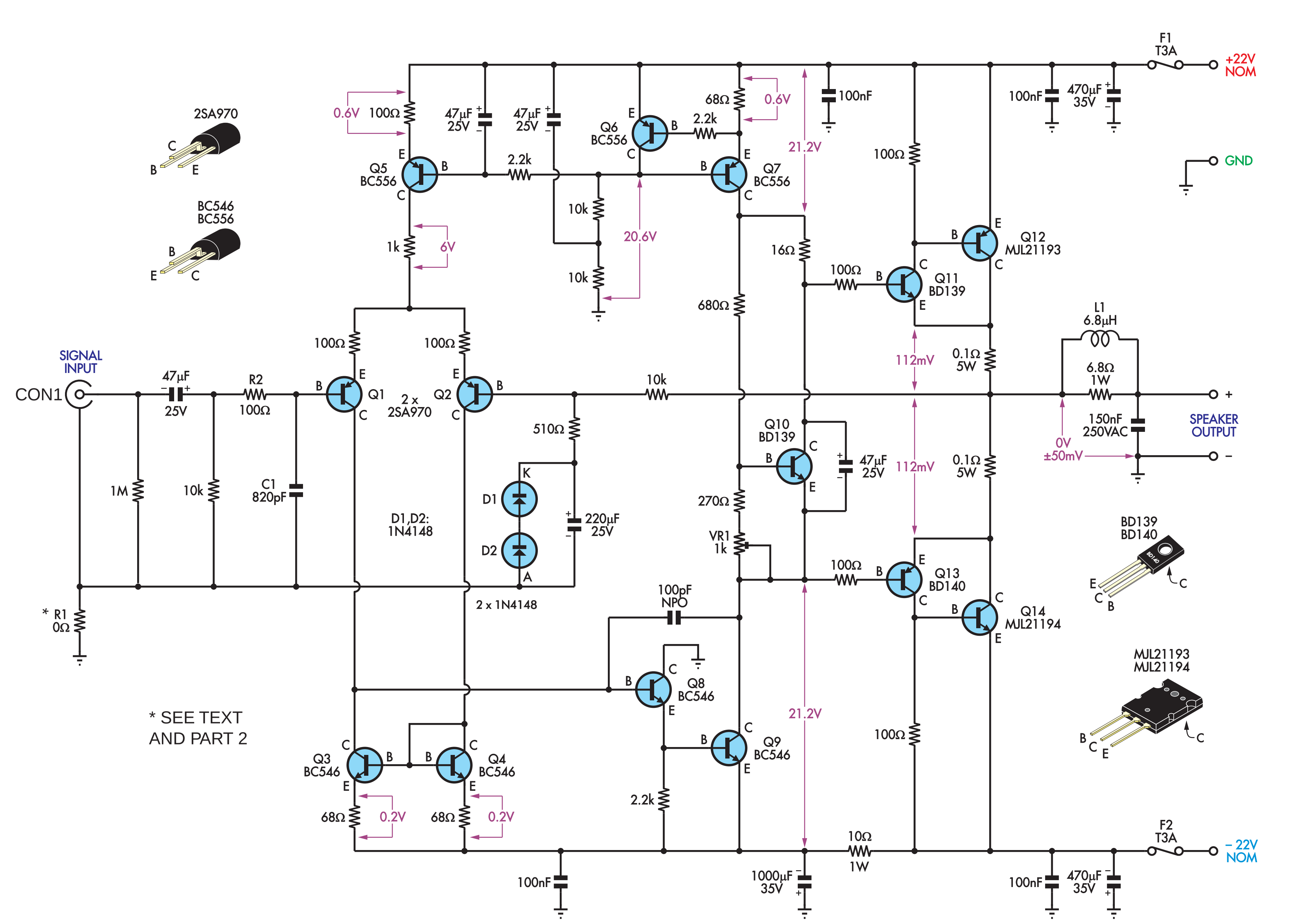
The output signal from voltage amplifier stage Q9 is coupled to driver transistors Q11 and Q13 via 100Ω resistors. These protect Q7 and Q9 in the event of a short circuit to the amplifier output, which could possibly blow these transistors before the fuses blow. The 100Ω resistors also have a secondary function in acting as 'stopper' resistors to help prevent parasitic oscillation in the output stage.

As already mentioned, the output stage actually uses complementary feedback pairs (CFP), based on Q11 and Q12 and Q13 and Q14. These give a more linear performance than the more usual Darlington transistor pairs used in many push-pull amplifiers. In effect, they are connected as feedback pairs with 100% current feedback from the collector of Q12 to the emitter of Q11 by virtue of a 0.1Ω 5Ω 'emitter' resistor.

To make the CFP concept easier to understand, consider transistor Q11 as a standard common emitter amplifier with a 100Ω collector load resistor. Transistor Q12's base emitter junction is connected across this 100Ω resistor, and so it becomes a current amplifier stage and its collector load is the common 0.1Ω resistor, which provides the current feedback to the emitter of Q11. Because there is 100% local feedback, these output pairs have unity gain and a very high degree of linearity.

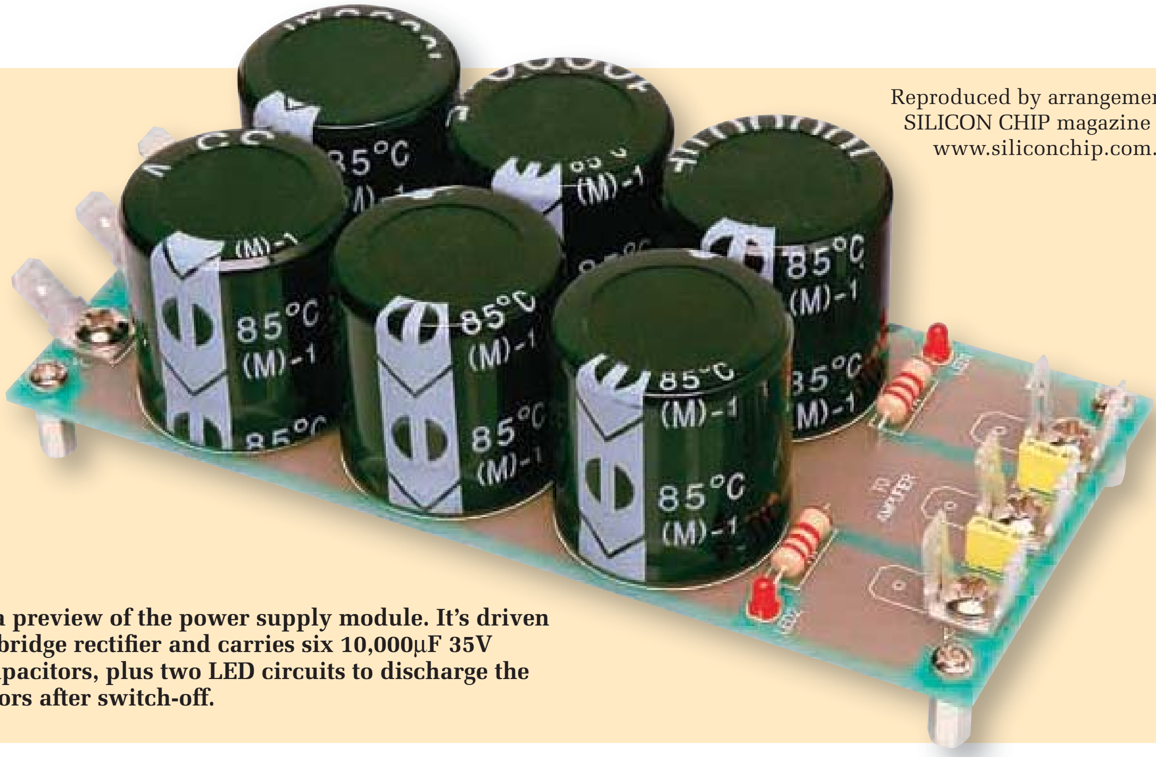
Output transistors

We should mention the output transistors specified for this amplifier. They are the MJL21193 and MJL21194 plastic encapsulated transistors. They are rated at 250V, 16A (30A peak) and 200W, and are clearly far more rugged than they need to be for an amplifier of this rating.



20W CLASS-A AUDIO AMPLIFIER

Fig.5: the circuit is a conventional direct-coupled feedback amplifier with complementary feedback pairs (Q11 and Q12, and Q13 and Q14) in the output stage. The V_{be} multiplier (Q10) is adjusted to give a quiescent current of 1.12A. The power supply details will appear in Part 2, next month.



Here's a preview of the power supply module. It's driven from a bridge rectifier and carries six 10,000µF 35V filter capacitors, plus two LED circuits to discharge the capacitors after switch-off.

We use them here because they are among the best complementary power transistors for linearity made by any manufacturer in the world (originally made by Motorola and now sourced from On Semiconductor – *Google*).

Another circuit change is that we have used a BD139 and a BD140 as the driver transistors in the complementary feedback pairs, instead of using the more usual lower power BC337 and BC327. This was necessary because of the higher power dissipation in the driver transistors.

Multiplier stage

Transistor Q10 is the V_{be} multiplier and it has exactly the same arrangement as in any class-B amplifier. A 'V_{be} multiplier' is a temperature-compensated floating voltage source and, in this case, it provides about 1.6V between the bases of Q11 and Q13. Q10 multiplies the voltage between its base and emitter, by the ratio of the total resistance between its collector and emitter to the resistance between its base and emitter.

In practice, trimpot VR1 is not adjusted to produce a particular voltage across Q10, but to produce the specified quiescent current of 1.12A in the output stage. This requires a voltage of 112mV across each 0.1Ω emitter resistor. In practice, the emitter resistors have a 5% tolerance, so we average the voltage across each of these resistors at 112mV.

Note that you will need a digital multimeter for this adjustment (more on this next month).

An interesting point about Q10 is that we have specified a BD139 for this task instead of a much lower-rated BC547 or similar transistor, which would certainly be adequate from the point of power dissipation. The reason for using the BD139 is that its package and junction does a much better job of tracking the junction temperature of the driver and output transistors and thereby gives much better bias stability. In fact, Q10 is bolted to the same heatsink as driver transistor Q11 to improve tracking.

Also included to improve temperature compensation is the 16Ω resistor in the collector circuit of Q10; a small point, but still worthwhile.

Output RLC filter

The remaining circuit feature to be discussed is the output *RLC* filter, comprising a 6.8µH air-cored choke, a 6.8Ω resistor and a 150nF 250V AC capacitor. This output filter was originally produced by Neville Thiele and is still the most effective output filter for isolating the amplifier from any large capacitive reactances in the load, thereby ensuring unconditional stability. It also helps attenuate any RF signals picked up by the loudspeaker leads and stops them being fed back to the early stages of the amplifier, where they could cause RF breakthrough.

Finally, as with any high-quality amplifier design, the PC board itself is a very critical part of the circuit and is a major factor in the overall performance. Even small deviations in PC layout can have major deleterious effects on the distortion performance.

That's all for now. In Part 2, we'll show you how to build the matching left and right amplifier modules and describe the power supply assembly. ***EPE***

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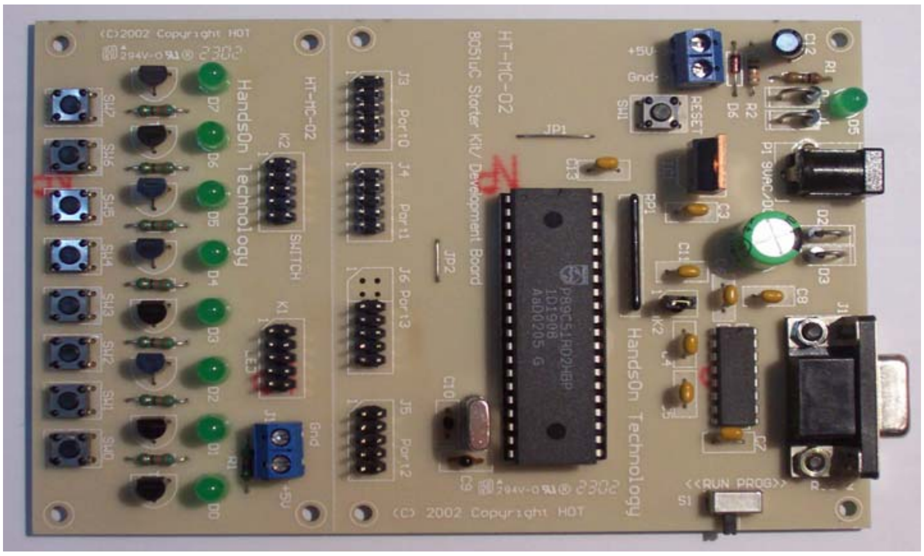

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- Boot ROM contains low level Flash programming routines for downloading code via the RS232.
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20W Class-A Amplifier Pt.2

This fully assembled chassis shows what the Stereo Class-A Amplifier will look like. The preamplifier/remote volume control module and the loudspeaker protection module will be described in following issues.

This month, in Part 2, we present the construction details for matching left and right channel mirror-image modules, together with the circuit and construction details of the power supply.

Part 2: By Leo Simpson

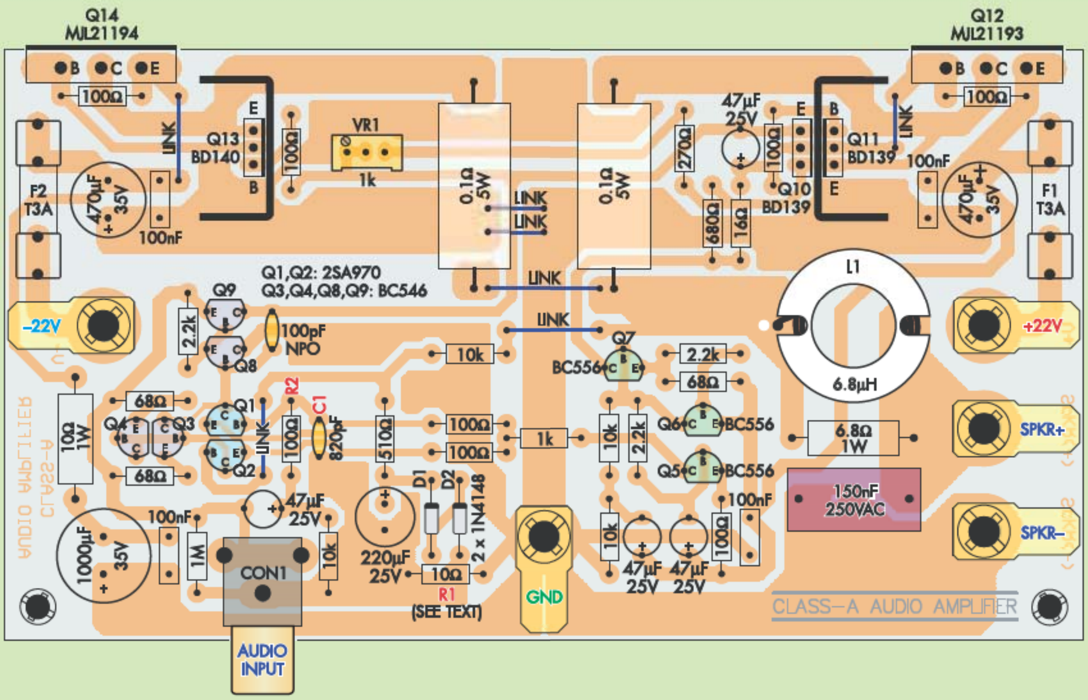


Fig.6: follow this parts layout diagram to build the left-channel power amplifier module. Be sure to use the correct part at each location and make sure that all polarised parts (transistors, diodes and electrolytic capacitors) are correctly installed.

THE PC boards are longer than the early original prototypes. This is mainly to spread the two power output transistors further apart on the large single-ended heatsinks. This has the effect of spreading the 'hot spot' and allows us to use the heatsinks more efficiently.

We have also designed mirror image PC boards, for the left and right channels. This has been done to achieve a better wiring layout within the amplifier chassis and also to optimise the residual noise performance in both channels.

Both PC boards measure 146 × 80mm and are coded 687 (left) and 688 (right). (These boards, including the power supply PCB, are available from the *EPE PCB Service*.) To ensure reliable connections to the PC boards, we have specified chassis-mount 'quick-connect' single-ended male spade terminals, which have a mounting hole for an M4 screw.

These connectors are normally used for high current connections, but we are using them here because we want to ensure very low resistance connections. They have the advantage over normal soldered connections to a PC board being able to be repeatedly connected and disconnected without problems, when an amplifier is being assembled and checked.

By the way, we do not recommend staked quick-connect spade lugs for this application, as they are not as reliable, particularly after they have been reconnected a few times.

With the same thought in mind about reliable terminations, the audio signal connection to each module is made via an on-board RCA phono socket. This is much better than using soldered connections for shielded cable, as they are bound to look messy after being disconnected and reconnected just once.

One module or two?

Before we start on the assembly details, there are a few other points to note. The first pertains to whether or not you are building a single PC board module to be used as a mono amplifier (unlikely, but we have to consider it). If so, note that R1 is a 0Ω link, as shown on the circuit diagram of Fig.5 in last month's issue.

Alternatively, if you are building left and right modules for a stereo amplifier, **R1 must be changed to a 10Ω resistor (in each channel).** This is done to reduce the possibility of circulating currents in the completed stereo amplifier, which could compromise the performance, particularly separation between channels.

Transistor quality

To ensure the published performance figures, the MJL21193 and MJL21194 power transistors must be On Semiconductor branded parts, while the 2SA970 low-noise devices must be from Toshiba. Be particularly wary of counterfeit parts, as reported in the past. We recommend that all other transistors used in this project be from reputable manufacturers, such as Philips, On Semiconductor and ST Microelectronics. This applies particularly to the BD139 and BD140 output drivers.

Construction

The component layouts for the mirror reverse boards are shown in Fig.6 (left) and Fig.7 (right).

Begin each board assembly by installing the wire links, the two 1N4148 diodes (D1 and D2), and the resistors and capacitors. The resistor colour codes are shown in Table 1, but we strongly advise

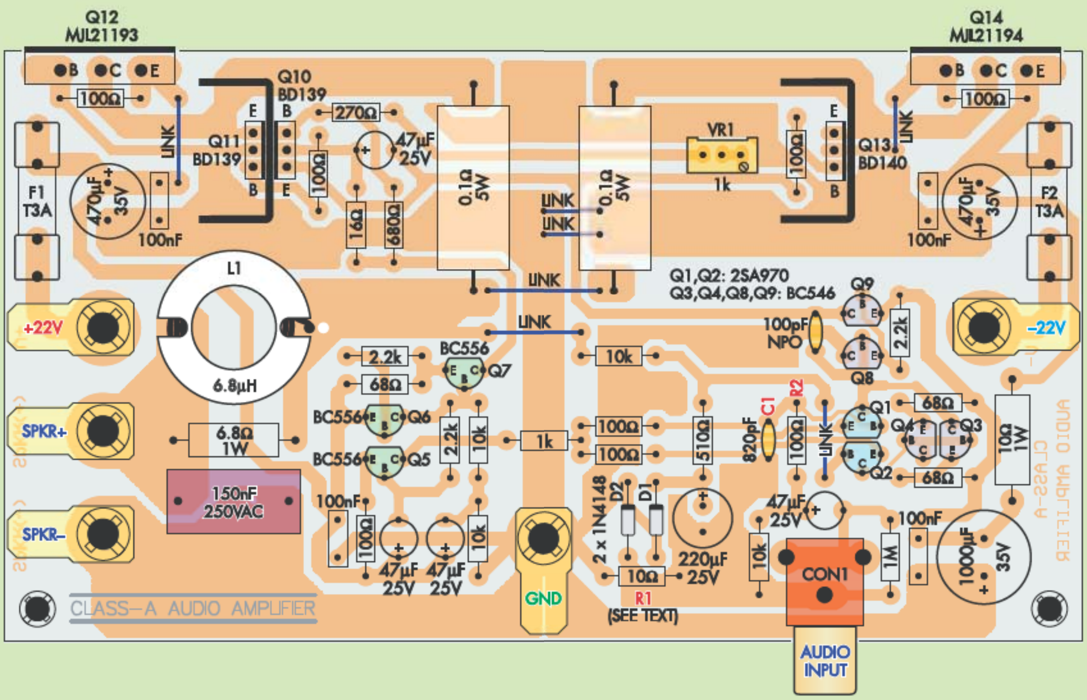


Fig.7: this is the layout for the matching right-channel power amplifier module. It's almost a mirror image of the left-channel board.

that you also check each value using a multimeter before it is installed.

Make sure that the diodes and electrolytic capacitors are installed with the correct polarity.

That done, you can then install the fuse clips. Note the each fuse clip has a little lug on one end which stops the fuse from moving lengthways. If you install the clips the wrong way around, those lugs will stop you from fitting the fuses.

Next, install the two 0.1Ω 5W resistors, followed by trimpot VR1. Trimmer VR1 must go in with its adjustment screw oriented as shown.

The small-signal (TO-92) transistors (2SA970s, BC546s and BC556s) can now be installed. As supplied, these transistors usually have their leads in a straight line, although the centre lead may sometimes be cranked out. They have to be splayed outwards and cranked to fit nicely into their allocated positions.

The way to do this is as follows. First, grip the three leads adjacent to the transistor body using a pair of needle-nose pliers and bend the centre lead back and up by about 70°. That done, grip each of the two outer leads in turn and bend it outwards and up by about 70°. Finally, grip each lead in turn at the end of the pliers and bend it downwards again – see photos.

Install each transistor on the PC board after dressing its leads. Note that transistor pairs Q1 and Q2, and Q3 and Q4 are installed with their flats facing each other.

Make sure that you don't install the TO-92 transistors in the wrong positions. Inadvertently swapping 2SA970s for BC556s will not have any dire consequences, except that the amplifier will not be as quiet as it would have been. But swapping BC546 *NPN* transistors for BC556 or 2SA970 *PNP*

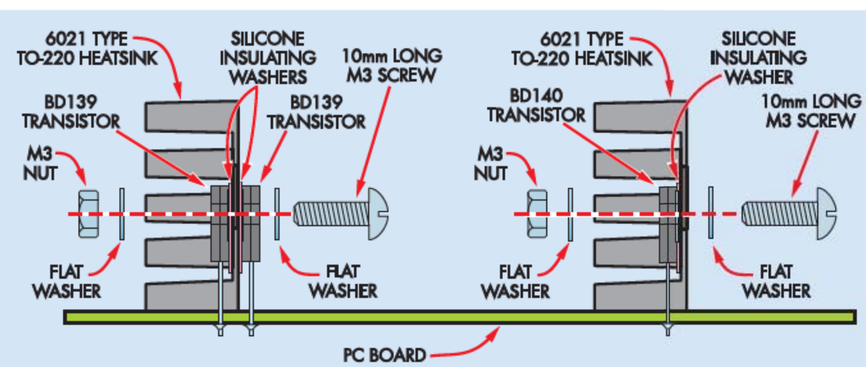
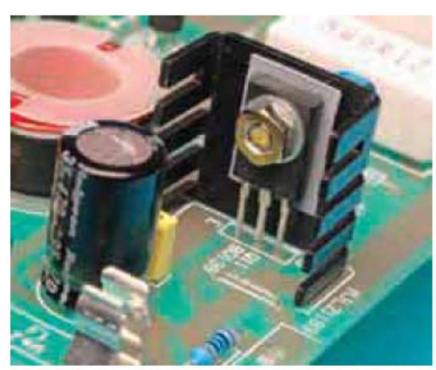
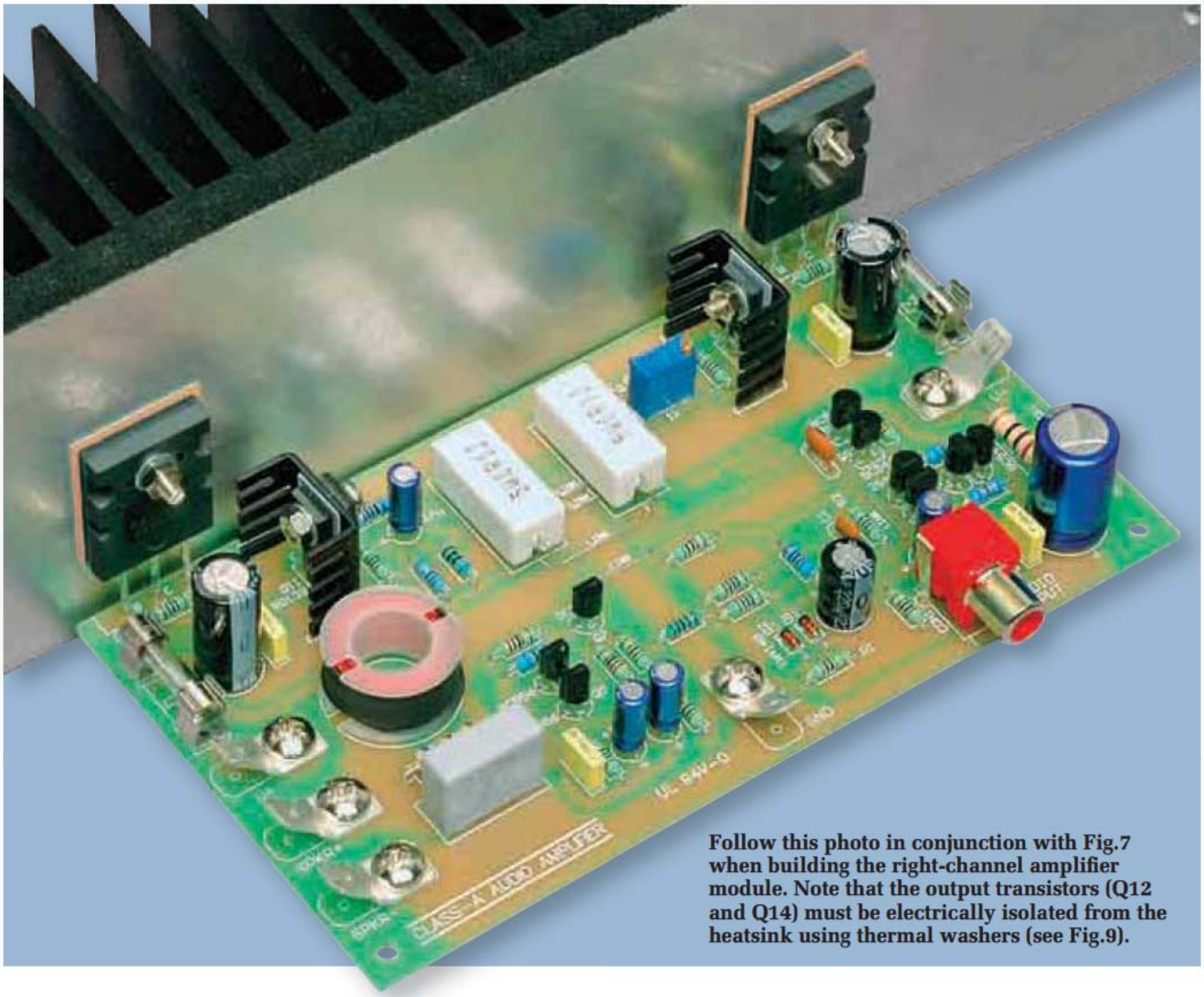


Fig.8: follow this diagram to attach the BD139 and BD140 transistors to their respective heatsinks. Note that each transistor is electrically isolated from its heatsink using a silicone insulating washer.



This close-up view shows one of the BD139 transistors (left-channel amplifier board). A second BD139 mounts on the other side of this heatsink.



Follow this photo in conjunction with Fig.7 when building the right-channel amplifier module. Note that the output transistors (Q12 and Q14) must be electrically isolated from the heatsink using thermal washers (see Fig.9).

transistors will cause serious damage when the amplifier is first powered up. ***You have been warned!***

The idea is to work carefully and patiently through the assembly process. Check each step against the diagrams and photos as you go. Care and patience now will be rewarded later when you turn the amplifier on.

The TO-126 transistors Q10, Q11 and Q13 are fitted to U-shaped finned heatsinks before they are soldered to the PC board. More specifically, Q10 and Q11, both BD139s, are mounted on opposite sides of the same heatsink (see Fig.8) while Q13, a BD140, is mounted on a separate finned heatsink. **Note that each transistor must have a silicone rubber pad to isolate it from the heatsink – see Fig.8 and the photos.**

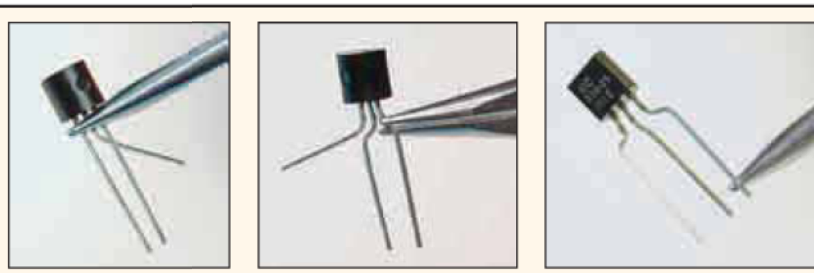
Note also that the 100pF ceramic capacitor at the collector of Q9 should be an NP0 type (ie, with zero temperature coefficient). NP0 capacitors have a black spot or strip across the top. If your 100pF capacitor does not have this black labelling, it is not NP0.

Other types may change their capacitance markedly with temperature, which is undesirable.

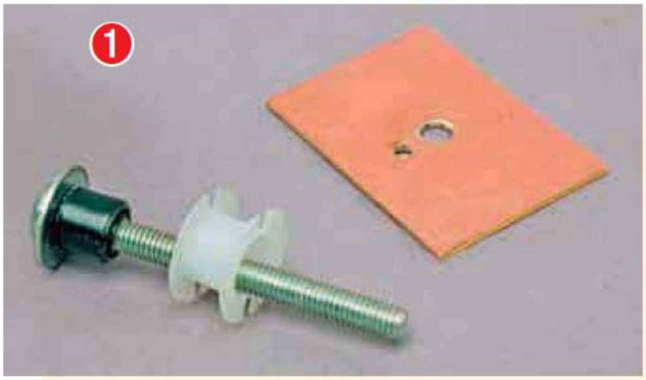
Winding jig

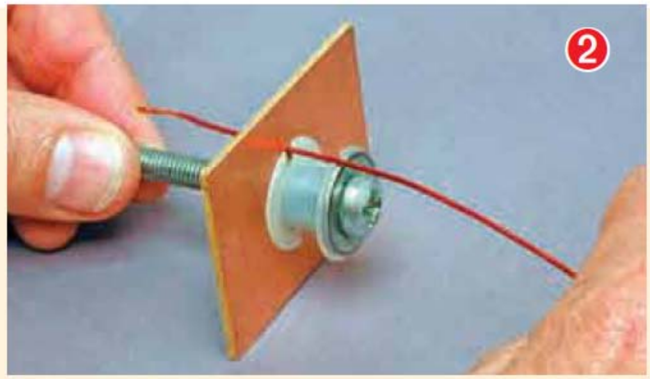
The next step is to wind the 6.8µH inductor L1. To do this, you need about 1.5m of 1mm enamelled copper wire, which is close-wound onto a plastic bobbin. This bobbin may have an internal diameter of either 11.8mm or 13.8mm, depending on the supplier.

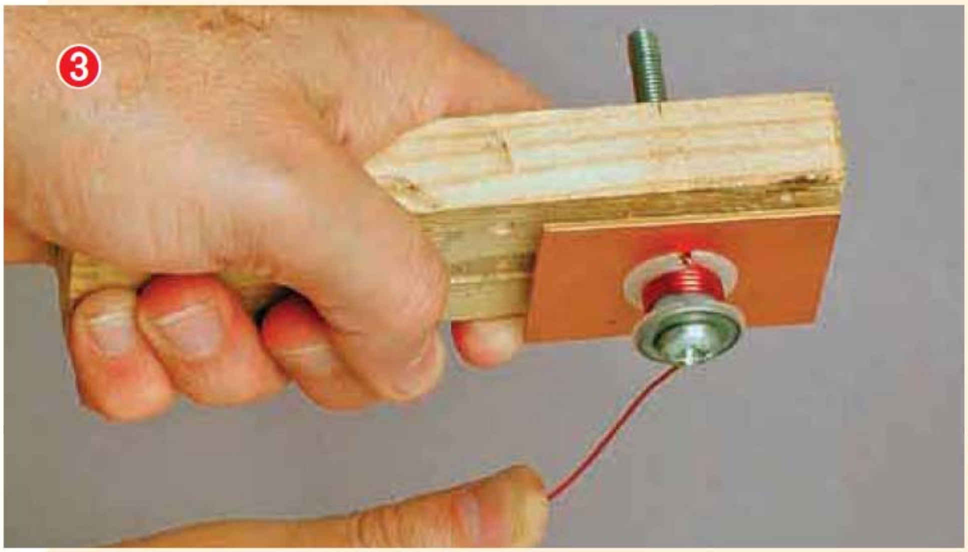
As shown in the photos, we made up a small winding jig for the bobbin, as this enables a really neat job. It consists of an M5 × 70mm bolt, two M5 nuts,



The leads of the TO-92 transistors are cranked to fit the PC board using a pair of needle-nose pliers. These photos show how it's done.







Above: these photos show how to make a simple jig from scrap material to wind the 6.8µH inductors (see text). First, the bobbin is slipped over the collar on the bolt (1), then the end cheek is attached and the wire threaded through the exit slot (2). The handle is then attached and the coil wound using 25.5 turns of 1mm enamelled copper wire (3). The finished coil (4) is secured using a couple of layers of insulation tape and a band of heatshrink tubing.

an M5 flat washer, a piece of scrap PC board material (40 x 50mm approx.) and a scrap piece of timber (140 x 45 x 20mm approx.) for the handle.

In use, the flat washer goes against the head of the bolt, after which a collar is fitted over the bolt to take the bobbin. This collar should be slightly less than the width of the bobbin and can be wound on using insulation tape.

Wind on sufficient tape so that the bobbin fits snugly without being tight.

Next, drill a 5mm hole through the centre of the scrap PC board material, followed by a 1.5mm exit hole about 8mm away that will align with one of the slots in the bobbin. That done, the bobbin can be slipped over the collar and sandwiched into position between the washer and the PC board (which acts as an end cheek).

Align the bobbin so that one of its slots lines up with the exit hole in the end cheek, then install the first nut and secure it tightly. The handle can then be fitted by drilling a 5mm hole through one end, then slipping it over the bolt and installing the second nut.

Winding the choke

Begin by feeding about 40mm of the wire through one of the bobbin slots and the exit hole in the jig (loosen the handle if necessary to do this). Bend this end back through 180° to secure it, then tighten the handle and wind on 25.5 turns as evenly and tightly as possible. Finish by bending the remaining wire length through 90° so that it aligns with the opposite slot.

Here's another view of the fully-assembled right-channel power amplifier module, attached to its heatsink. After mounting the output transistors, it's a good idea to use a multimeter (set to a high ohms range) to confirm that they are correctly isolated from the heatsink. You should get an open-circuit reading between the heatsink and each of the transistor leads.

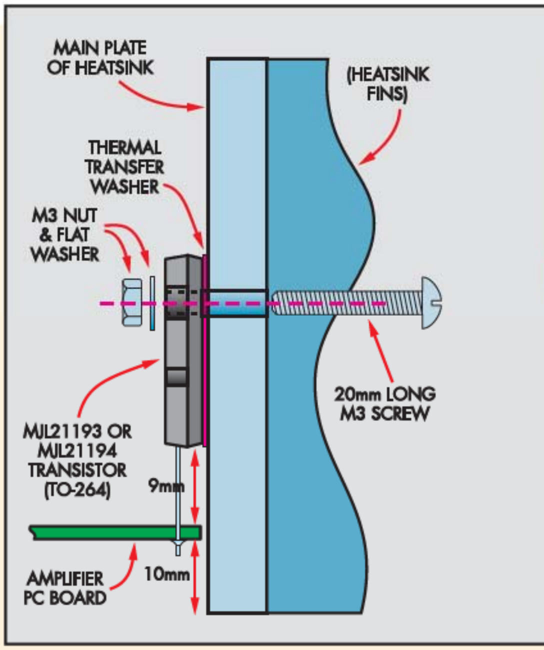
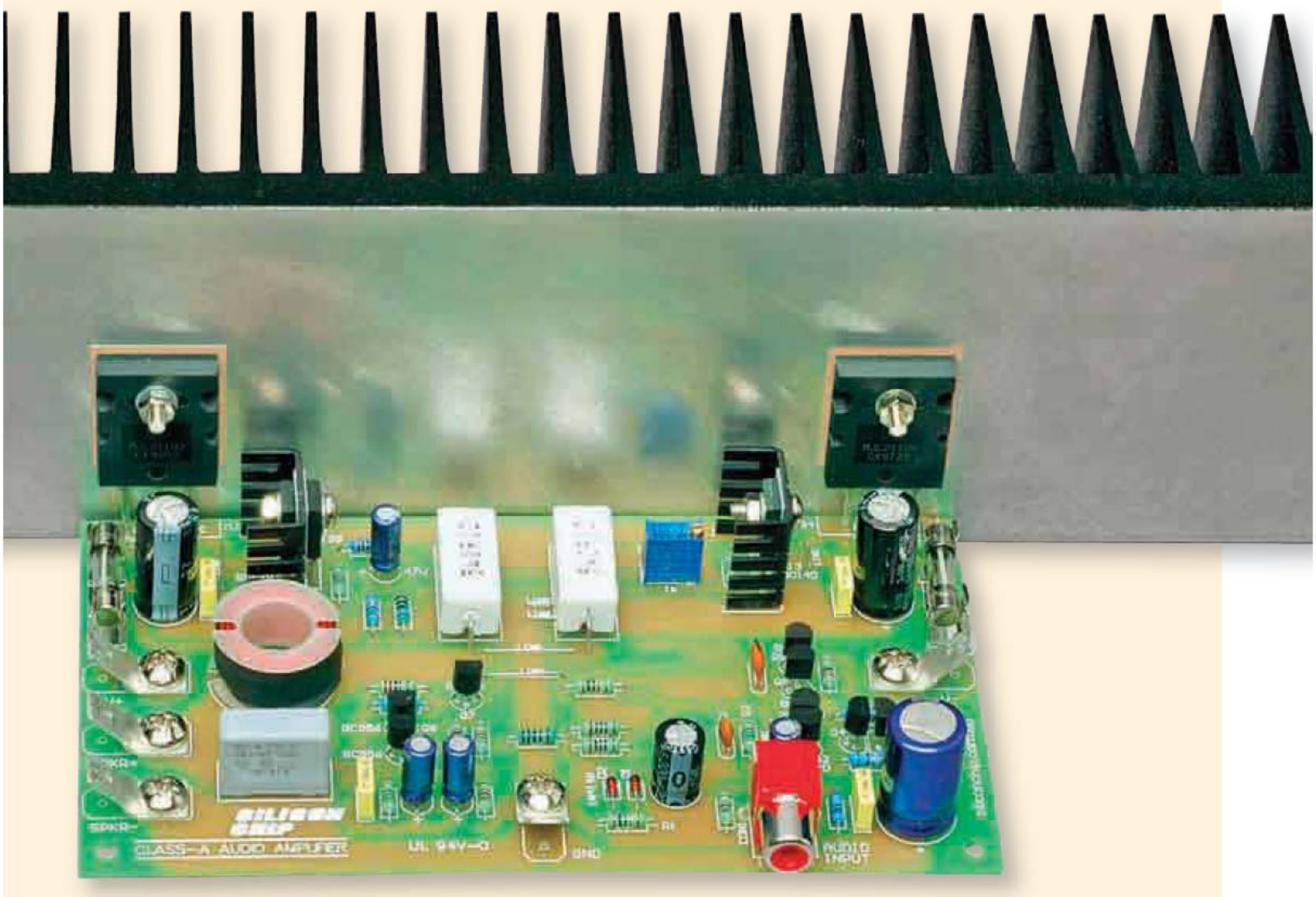


Fig.9: this diagram shows the mounting details for the output transistors (left), along with the heatsink drilling diagram (above). Note that the transistors are mounted with a lead length of 9mm using the method detailed in the text. Be sure to deburr the mounting holes using an oversize drill, to prevent punch-though of the insulating washers.



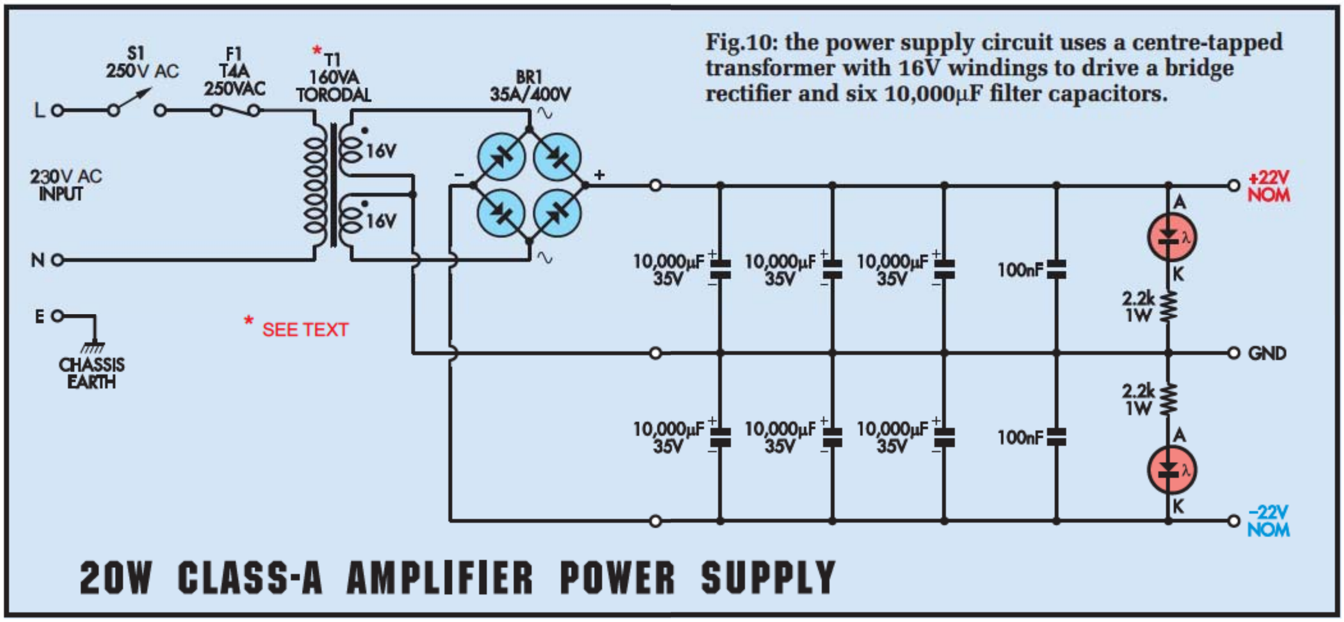


Fig.10: the power supply circuit uses a centre-tapped transformer with 16V windings to drive a bridge rectifier and six 10,000µF filter capacitors.

The windings can now be secured using a couple of layers of insulation tape, after which the bobbin can be removed from the jig. Cut off the excess wire at each end, leaving about 10mm protruding.

Finally, complete the choke by fitting some 20mm diameter (9mm wide) heatshrink tubing over the windings. Be careful when shrinking it down with a hot-air gun – too much heat will damage the plastic bobbin.

You can now test fit the finished inductor to its PC board, bending its leads as necessary to get the bobbin to sit down flush on the board. It's then just a matter of stripping the enamel from the wire ends and tinning them before soldering the choke in place.

Power transistors

The two output transistors must be installed with their plastic bodies exactly 9mm above the surface of the PC board. In practice, you have to first mount the two transistors on the heatsink.

The mounting details for each device is shown in Fig.9. **Note that it is necessary to use a thermal insulating washer to electrically isolate each device from the heatsink.**

First, check that the mounting areas are smooth and free of metal swarf (deburr the holes if necessary using an oversize drill), then loosely secure each device to the heatsink using an M3 × 20mm machine screw, flat washer and nut. That done, cut a couple of 9mm wide cardboard spacers about 40mm long – these will be used to space the transistor bodies off the PC board.

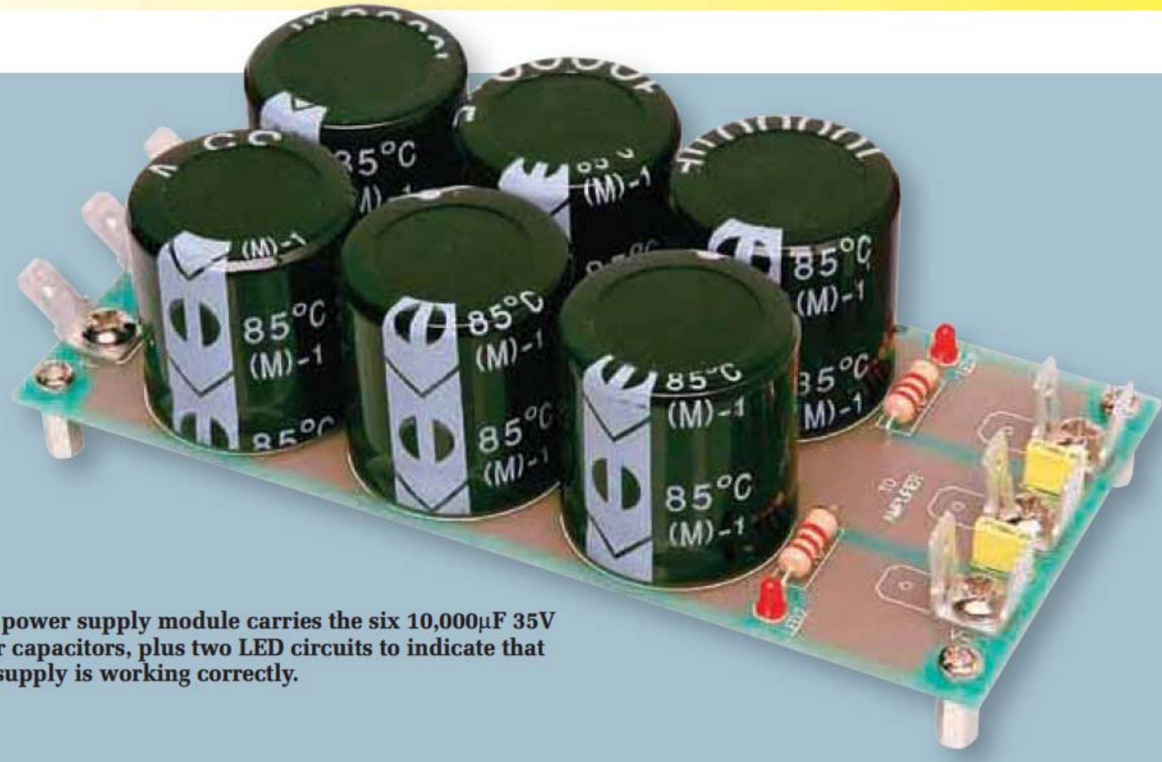
Next, turn the heatsink assembly upside down and slip the PC board (upside down) over the transistor leads. Push the board down so that the cardboard spacers are sandwiched between the board and the transistor bodies, then line everything up square and lightly tack solder the centre lead of each device.

It's important to now check that everything lines up correctly. The PC board should sit exactly 10mm below the edge of the heatsink, while each end of the board should be 77mm from its adjacent heatsink end (it helps to mark these points beforehand).

Make any adjustments as necessary, then complete the soldering and trim the device leads. That done, you can

Table 1: Resistor Colour Codes

❑	No.	Value	4-Band Code (1%)	5-Band Code (1%)
❑	1	1MΩ	brown black green brown	brown black black yellow brown
❑	4	10kΩ	brown black orange brown	brown black black red brown
❑	3	2.2kΩ	red red red brown	red red black brown brown
❑	1	2.2kΩ 1W 5%	red red red gold	NA
❑	1	1kΩ	brown black red brown	brown black black brown brown
❑	1	680Ω	blue grey brown brown	blue grey black black brown
❑	1	510Ω	green brown brown brown	green brown black black brown
❑	1	270Ω	red violet brown brown	red violet black black brown
❑	8	100Ω	brown black brown brown	brown black black black brown
❑	3	68Ω	blue grey black brown	blue grey black gold brown
❑	1	16Ω	brown blue black brown	brown blue black gold brown
❑	1	10Ω 1W 5%	brown black black gold	NA
❑	1	6.8Ω 1W 5%	blue grey gold gold	NA



The power supply module carries the six 10,000μF 35V filter capacitors, plus two LED circuits to indicate that the supply is working correctly.

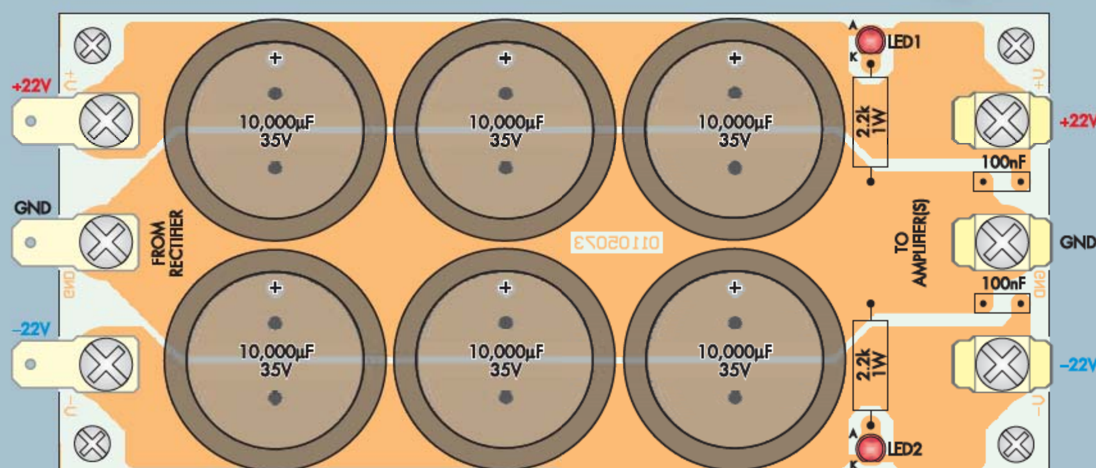


Fig.11: here's how to build the power supply board. Install the quick-connect terminals first so that there's no risk of damaging the expensive 10,000μF capacitors if a tool slips while tightening the screws. The capacitors can then go in, followed by the resistors and the LEDs.

tighten the mounting screws that secure the transistors to the heatsinks, making sure that the insulating washers are correctly aligned. These screws should be tight to ensure good thermal coupling between each device and the heatsink.

Finally, check that each device is electrically isolated from the heatsink using a multimeter. You should get an open-circuit reading between each device lead and the heatsink metal.

By the way, we recommend high-efficiency thermal insulating washers for the MJL21193 and MJL21194 output devices (see last month's parts list). Typical low-cost silicone rubber washers performed poorly in tests, resulting in at least 5°C higher transistor running temperatures.

On a similar theme, adequate airflow up through the heatsink fins is vital to amplifier survival and long-term reliability. This means that the amplifier must be operated in a well-ventilated area – those heatsinks do get hot (typically 30°C above ambient).

That completes the assembly details of the power amplifier modules. Next, we need to discuss the power supply circuit and construction of the power supply module.

Shielded power transformer

As noted last month, this design dispenses with a regulated power supply and uses a bridge rectifier and a bank of filter capacitors. Fig.10 shows the circuit diagram. As can be seen, it employs a centre-tapped transformer with 16V windings to drive a bridge rectifier and six 10,000μF 35V electrolytic capacitors (30,000μF on each side) to provide balanced ±22V DC supply rails.

Also included in the power supply circuit are two LEDs and two 2.2kΩ resistors to provide a visible indication

continued on page 40

Measuring ultra-low harmonic distortion

How good are our new Class-A audio amplifier modules? Well, they are too good to measure on our Audio Precision test gear, as we explain.

In a previous class-A amplifier article, we noted the great difficulty in measuring the very low distortion of the circuit. The main problem is that at lower power levels, circuit noise tends to completely obliterate the measurement. Even at full power (20W), the noise in the signal is quite significant.

To put that into perspective, the signal to noise ratio of the new amplifier with respect to full power is –115dB unweighted (ie, with a noise bandwidth from 22Hz to 22kHz) which is very, very low. How low? Think of a noise signal which is only 22 microvolts! Compare that with the total harmonic distortion which is typically 0.0006% (–104dB or 76µV) and you can see that noise is a significant part of the measurement.

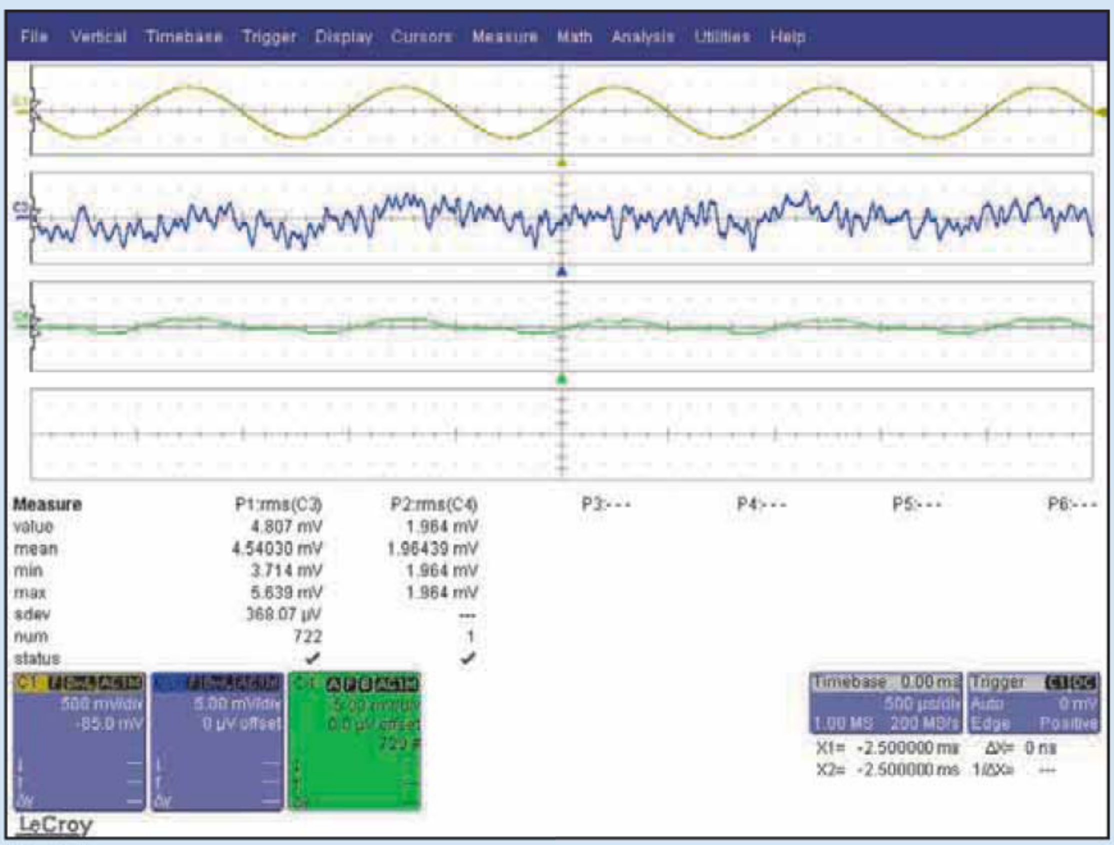
In the previous article we demonstrated a method to remove the noise component of a THD (total harmonic distortion) signal using the averaging feature of a Tektronix TDS360 digital scope. The noted audio designer Douglas Self devised this method. This technique can filter out virtually all the random noise signal to leave the harmonic content displayed.

Fast-forward to the present, and we can do the same procedures using our vastly more capable LeCroy WaveJet 2Gs/s 200MHz digital oscilloscope. We often feature screen grabs from this scope to demonstrate circuit performance.

However, the LeCroy WaveJet does not allow us to perform normal sampling and averaging on the same signal simultaneously and we wanted to do this in order to more clearly demonstrate the dramatic effect of noise averaging using a digital scope. What to do?

It turns out that LeCroy have a much higher performance scope which would let us do this procedure. We managed to gain access to a LeCroy WaveRunner 10Gs/s 600MHz scope.

We performed three tests to demonstrate the extremely high performance of our new amplifier. The accompanying three scope screen grabs each show three signal traces. In each case, the top trace is the fundamental – ie, a 1kHz sinewave. The trace below that is the residual THD signal after the fundamental 1kHz sinewave has been nulled out by our Audio Precision automatic distortion test set. Both these



Scope1: the THD measurement of the amplifier at 1kHz and 20W. Note the much cleaner averaged bottom trace (green).

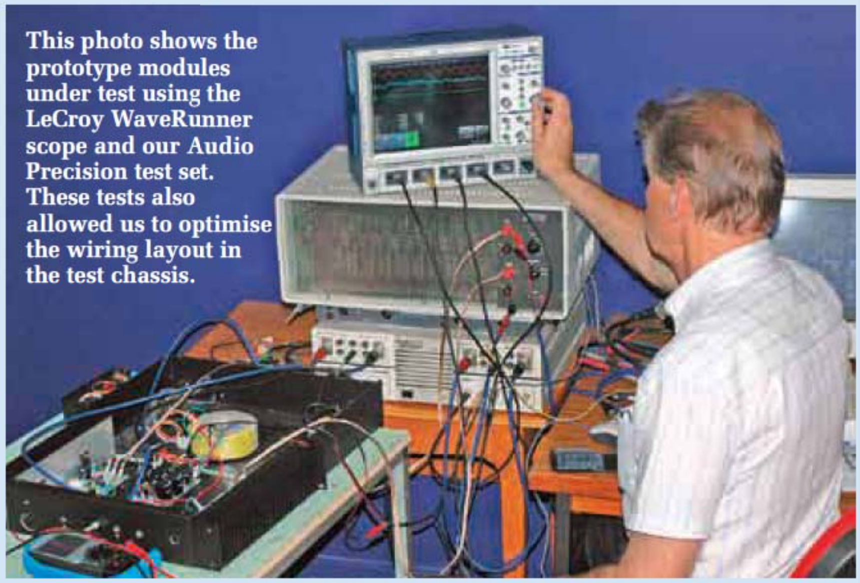
traces are displayed using normal scope sampling, so all the noise in the signal is clearly shown as a large random component.

The bottom trace is displayed using the averaging technique and is in fact the average of 128 sweeps of the trace. Furthermore, we have applied a degree of digital filtering to limit the noise in the displayed signal.

Scope1 shows the measurement of the new amplifier at 20W. The total harmonic distortion was 0.00056%.

To explain this, the middle trace represents an RMS voltage which is 0.00056% of 12.69V, the signal level needed for 20W into an 8-ohm load. As presented on the scope, the middle trace has a mean (ie, average) value of 4.54mV RMS. Now look at the averaged trace (bottom). Not only is it almost completely devoid of random noise (revealing the true harmonic content) but its RMS value is only 1.96mV RMS. This enables us to recalculate the true harmonic distortion to around 0.00024%! Wow.

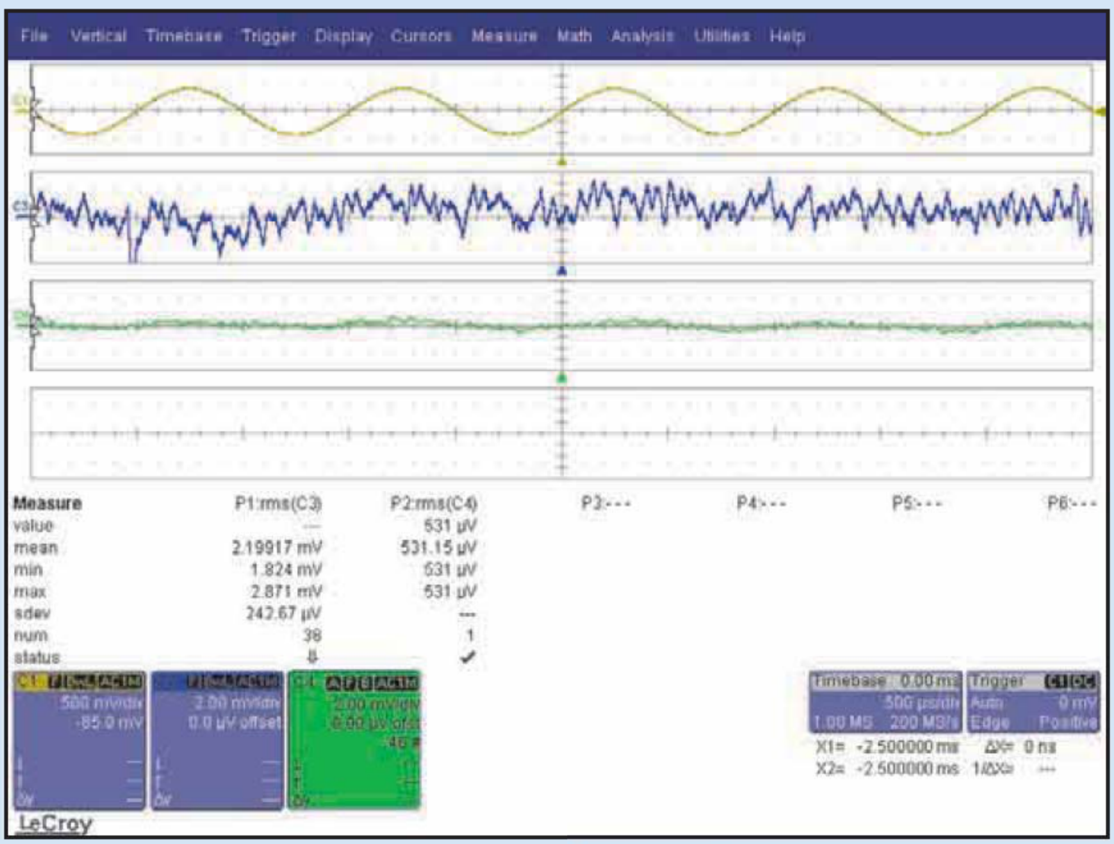
By the way, the scope displays a full set of measurements for channel



This photo shows the prototype modules under test using the LeCroy WaveRunner scope and our Audio Precision test set. These tests also allowed us to optimise the wiring layout in the test chassis.

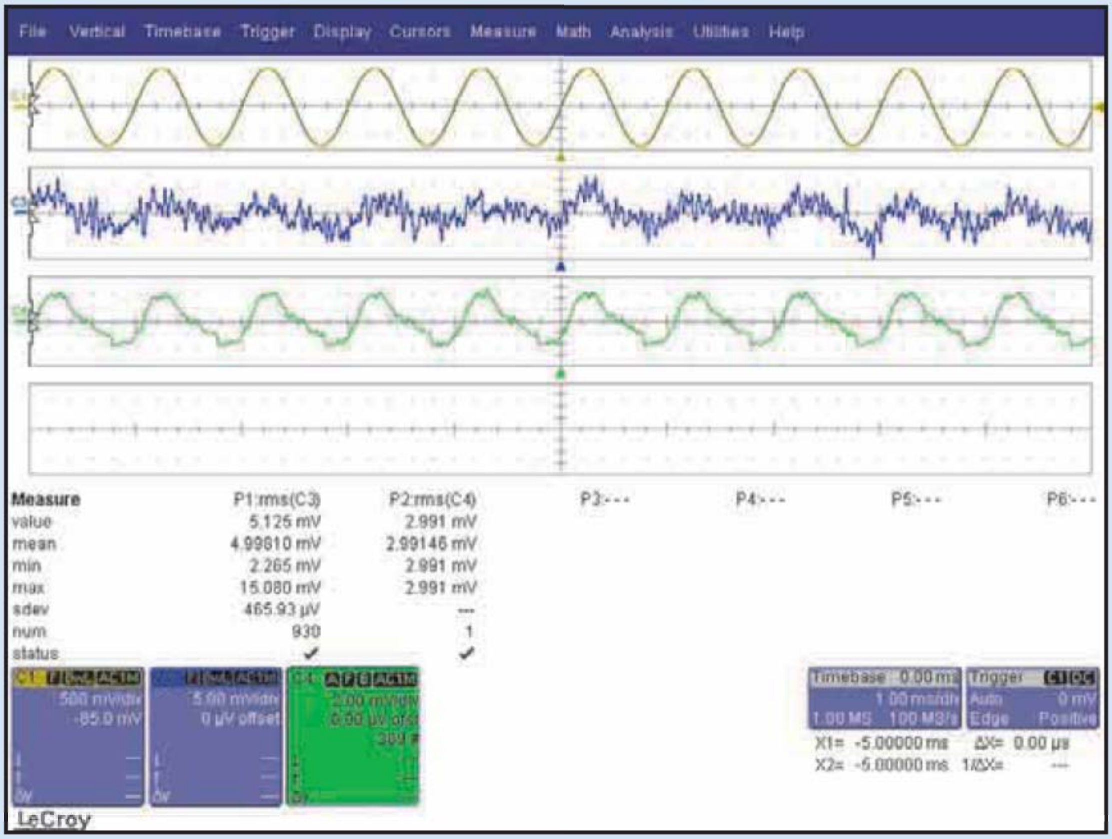
3 (blue) and channel 4 (green), including instantaneous value, mean, min, max and standard deviation.

Scope2 is even more dramatic, as it demonstrates the THD measurement at a power level of 1W. Here, the measurement is 0.001%, much worse than for full power, but in this case the fixed residual noise level of around 22µV is much more significant compared to the THD residual, which is 56µV. In this case, the THD trace is 2.2mV RMS compared to the averaged trace (bottom) of 531µV. Recalculating the harmonic distortion in the same way again gives



Scope2: the THD measurement of the amplifier at 1kHz and 1W. Here the residual noise (trace 2 – blue) is much greater and the averaged trace (green) is much cleaner.

0



Scope3: the THD measurement of the Audio Precision test set at 1kHz and 600mV.

Measuring ultra-low distortion: continued from previous page

a result of 0.00024%. This clearly shows that the harmonic distortion does not increase when the power level of the amplifier is reduced.

Well, that's great, but it is not the whole story, because when we measure the Audio Precision distortion test set itself, its THD is 0.0004% at 1kHz at a level of 600mV. Scope3 shows the equivalent process and after averaging the harmonic distortion, the reading is 0.00024%. But isn't that the same as the above readings for the amplifier? Yep. So in fact, we don't know how good the amplifier really is. Based on these figures, it might be less than 0.0001% but we have no way of knowing.

As a further exercise, we were able to do spectrum analysis using the LeCroy WaveRunner's FFT facility. However, while that showed the first harmonic content at down below 0.0001% for the Audio Precision's generator and similar low figures for the amplifier, the tests simply did not let us make any further estimates.

By the way, measuring a level of 0.0001% with respect to a 600mV signal actually refers to a signal component of just 6µV. The FFT analysis was able to measure harmonics out to the 19th, at much lower levels, so we were looking at harmonic components as little as −130dB with respect to the fundamental signal level. This is far below the amplifier's residual noise level; such is the capability of the LeCroy WaveRunner oscilloscope. It has 11-bit precision, enabling accurate measurements even at just a few microvolts.

So when you look at the overall harmonic distortion figures published in Part 1 (and to be published in future months for the completed stereo amplifier) remember that they don't tell the true story. This amplifier is actually too good for us to measure properly.

that power is present on the supply rails. This is very handy when you are working on the amplifier. Finally, there are two 100nF MKT polyester capacitors to provide a high frequency bypass filter on each supply.

However, the real feature of the power supply is the magnetically-shielded toroidal power transformer. Most people would be aware that standard toroidal power transformers have quite a low leakage inductance and therefore little hum radiation when compared to conventional EI laminated transformers. That is correct, but the hum radiation from a standard toroidal power transformer is still not low enough when used in conjunction with these high performance class-A amplifier modules.

Because of the constant power demand of about 100W drawn by the two modules, the transformer still has quite a significant hum field and this is a real problem when it is operated in close proximity to the amplifier modules. Our solution in an earlier design was to use a separate power box, to keep the transformer well away from the modules.

This life-size view shows the fully assembled left-channel amplifier module. Note that some minor changes were made to the PC board (just to the right of the audio input phono socket) after this module was assembled

However, this time around, we are specifying a shielded toroidal transformer, to keep the leakage inductance much lower. This employs a number of long strips of grain-oriented steel wound around the outside of the finished transformer and then covered in several layers of insulation. The unit looks just like any other toroidal transformer, but the hum field is much lower.

In addition, the transformer is oriented to give the best performance when it is finally installed in the chassis. As shown in the Performance panel last month, the end result is excellent, with extremely impressive signal-to-noise ratios and harmonic distortion figures.

The 16V + 16V 160VA magnetically sheilded toroidal transformer used in the model came from Altronics (**www.altronics.com**), who also supply kits for this project.

Power supply assembly

The PC board for the power supply accommodates the capacitors, the two LEDs, their resistors and that's it. The 35A bridge rectifier mounts on the chassis, which is necessary to remove the significant amount of heat it produces.

The power supply PC board is coded 689 and measures 135 x 63mm. As with the amplifier modules, all the connections to it are made via chassis-mount 'quick-connect' male spade terminals, which have a mounting hole for an M4 screw.

Fig.11 shows the component layout on the PC board. Install the quick-connect terminals first. As shown, three doubled-ended terminals are installed at the DC end of the board (ie, the same end as the LEDs), while three single-ended terminals are installed at the bridge rectifier end.

Once all the quick-connect terminals have been tightly secured to the PC board, you can then install the six PC-mount electrolytic capacitors. Make sure that you mount them with the correct orientation, otherwise there will be an almighty bang when you first turn on the power!

Finally, mount the MKT capacitors, the resistors and the two red LEDs. That's it – the power supply board is complete.

Next month

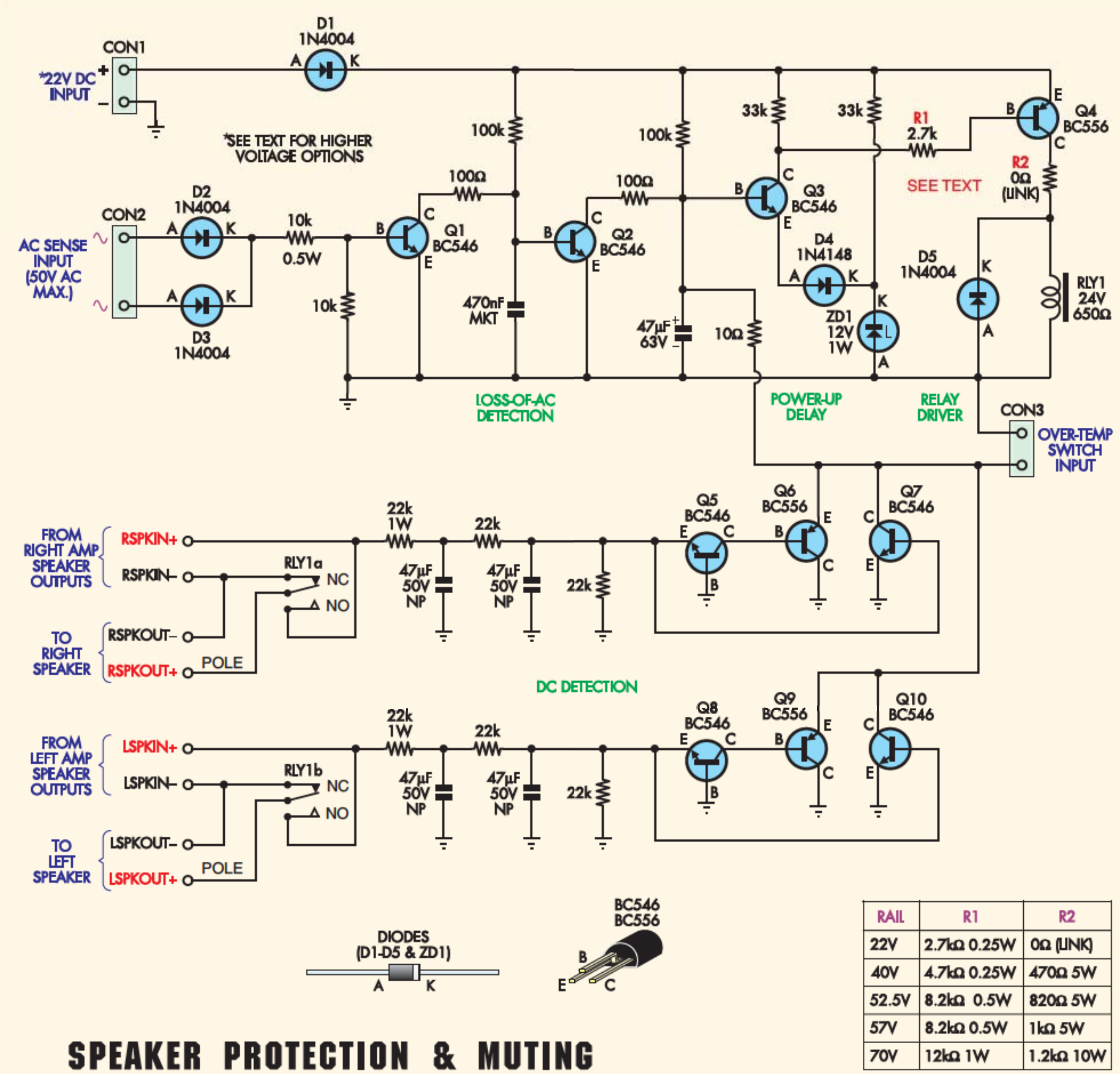
Next month, we will describe and construct the Loudspeaker Protector module. In the meantime, **don't be tempted to power up the amplifier modules** – there's a set procedure to follow with regards to setting the quiescent current through each output stage. ***EPE***

20W Class-A Amplifier Pt.3

Universal Speaker Protection and Muting Module

Designed for use in our Class-A Stereo Amplifier, this Speaker Protection and Muting Module is really a universal unit. It can be used with other amplifier modules and commercial stereo amplifiers and protects the loudspeakers in the event of a catastrophic amplifier failure. The module also mutes the loudspeakers at switch-on and switch-off to prevent those scary thumps.

By Greg Swain and Peter Smith



RAIL	R1	R2
22V	2.7kΩ 0.25W	0Ω (LINK)
40V	4.7kΩ 0.25W	470Ω 5W
52.5V	8.2kΩ 0.5W	820Ω 5W
57V	8.2kΩ 0.5W	1kΩ 5W
70V	12kΩ 1W	1.2kΩ 10W

Fig.1: each channel of the amplifier is monitored for DC faults by three transistors – Q5, Q6 and Q7 for the right channel and Q8, Q9 and Q10 for the left channel. If a DC signal is detected, Q3's base is pulled low, turning it off along with Q4 and the relay. Transistors Q1 and Q2 provide the switch-off muting feature. If the 'AC Sense' input voltage ceases, Q1 turns off, and Q2 turns on, which again pulls Q3's base low and turns off Q4 and the relay.

ALTHOUGH DESIGNED specifically for our Class-A Stereo Amplifier, this unit can actually be used with any audio amplifier with supply rails up to about 70V DC, simply by selecting two resistor values to suit.

Basically, the unit provides the following features:

1) It protects the loudspeakers against catastrophic failure in the amplifier – eg, if an output transistor goes short circuit

2) It provides muting at switch-on and switch-off, to prevent thumps from the loudspeakers

3) It provides an input for an over-temperature switch to disconnect the loudspeakers if the output stage heatsink temperature rises above a certain level.

Note, however, that this last feature is not used in the Class-A Stereo Amplifier. This is because its heatsinks run hot all the time (about 30°C above ambient) and disconnecting the loudspeakers does nothing to cool them down, since the output stage in each amplifier module draws a constant 1.12A – equivalent to a power dissipation of just under 50W.

By contrast, disconnecting the loudspeaker from a class-B amplifier will immediately reduces the current through the output stage to the quiescent current setting – typically around 50mA (assuming that there's no fault

This view shows how the unit is mounted in the rear lefthand corner of the Class-A Stereo Amplifier metal cabinet.

in the amplifier). So, for a class-B amplifier, it makes sense to use over-temperature sensing. If the heatsink to which the output transistors are attached gets too hot, disconnecting the loudspeakers immediately reduces the dissipation to just a few watts, which allows the heatsink to cool.

Note that the loudspeakers are connected (and disconnected) using a heavy-duty double-pole relay. We'll have more to say about that later.

Protecting the loudspeakers

By far the biggest reason for incorporating speaker protection into an amplifier is to prevent further damage in the case of a serious amplifier fault. For example, if the main supply rails are ±70V DC. This means that if one of the output transistors fails and there's no loudspeaker protection, more than 70V DC would be applied to the speaker's voice coil.

In a nominal 8Ω speaker, the voice coil has a DC resistance of around 6Ω and so the power dissipation would be around 800W, until the supply fuse blew. In the meantime, this amount of applied DC power is likely to push the voice coil out of its gap, damaging the voice coil and suspension in the process. And if the on-board supply fuse didn't blow fairly quickly, the voice coil would quickly become red-hot and could set fire to the speaker cone material.

This risk applies to any audio power amplifier of more than about 40W per channel. So a loudspeaker protection circuit is a very good idea.

The risk of setting fire to the loudspeaker is nowhere near as great with the Class-A Stereo Amplifier because the supply rails are just ±22V. In this case, a shorted output transistor would result in a dissipation of about 80W in the speaker's voice coil. It might not be enough to cause a fire, but it's certainly high enough to damage the loudspeaker by burning out the voice coil.

Muting the thumps

Muting switch-on and switch-off thumps is another important function of this unit.

Switch-on thumps are eliminated by using a simple circuit to delay the relay from turning on when power is first applied. This way, the amplifier modules are able to power up and settle down before the relay switches on (after about five seconds) to connect the speakers.

By contrast, switch-off thumps are eliminated by using an 'AC Sense' input to monitor the secondary AC voltage from the transformer (up to 50V AC max). When this AC voltage disappears (ie, at switch-off), the circuit switches the relay off in less than 100ms.

This is much faster than simply relying on the collapsing DC supply rail to turn the relay off. In practice, this could take half a second or more, as the main filter capacitors discharge – more than long enough for a any switch-off thumps to be audible.

Circuit details

Refer now to Fig.1 for the full Speaker Protection and Muting Module circuit details. As shown, each channel of the amplifier is connected to the NC and NO (normally closed and normally open) contacts of a relay. The relay wipers (poles) and NC contacts then each respectively connect to the positive and negative loudspeaker terminals.

Each channel of the amplifier is monitored for DC faults by a triplet of transistors – Q5, Q6 and Q7 for the right channel and Q8, Q9 and Q10 for the left channel. We'll describe the operation of the right channel only, as the circuit for the left channel is identical.

As shown, the active signal from the amplifier's right channel is fed to a low-pass filter consisting of three 22kΩ resistors and two 47µF 50V bipolar (BP or NP) electrolytic capacitors. This network removes any audio frequencies and just leaves DC (if present under fault conditions) to be monitored by the three transistors,

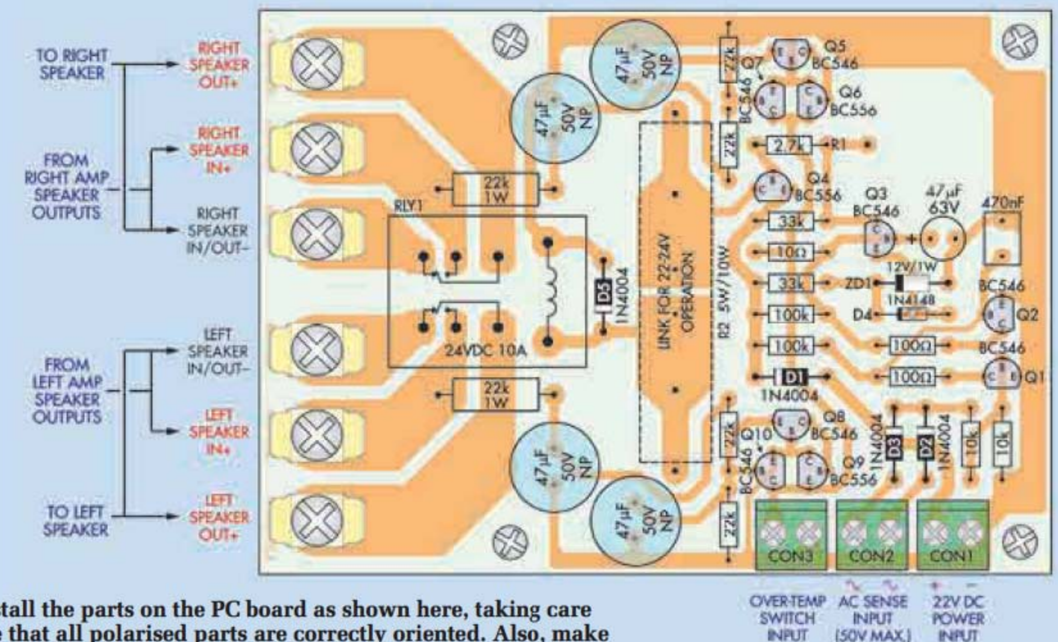
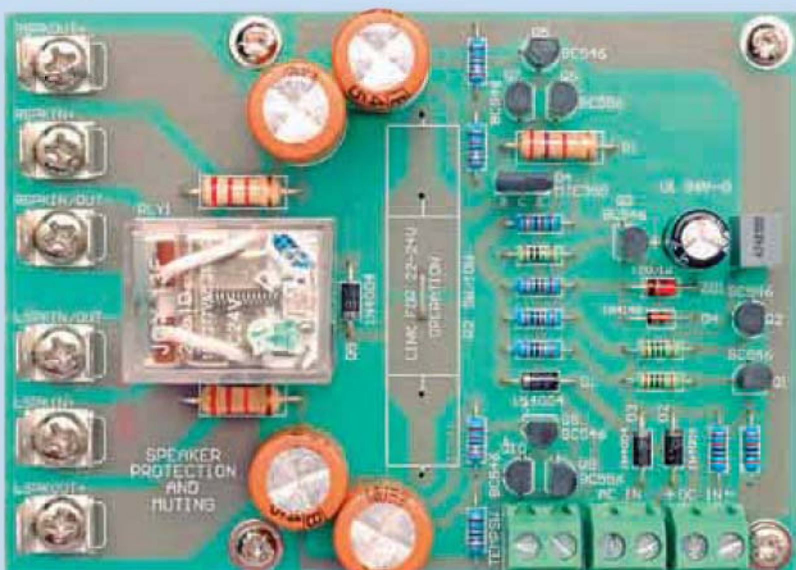


Fig.2: install the parts on the PC board as shown here, taking care to ensure that all polarised parts are correctly oriented. Also, make certain you use the correct transistor type at each location. Below is the completed PC board.



Q5, Q6 and Q7. This is because we don't want audio signals to trip the protection circuit.

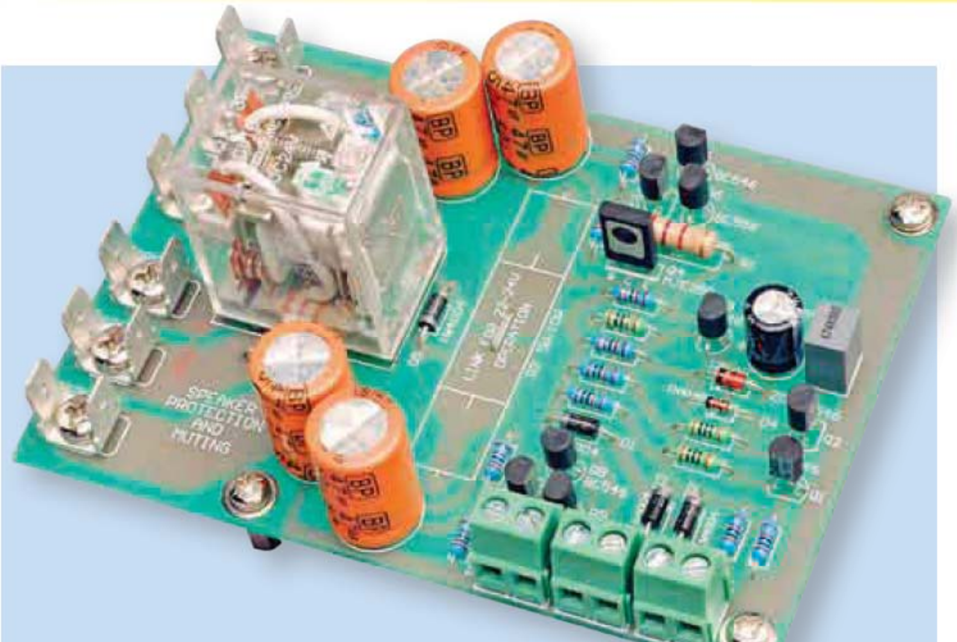
The low-pass filter output is connected to the emitter of Q5 and to the base of Q7. Transistor Q5 monitors the amplifier output for negative DC signals, while Q7 monitors for positive DC signals.

In operation, transistor Q7 turns on if a DC signal of more than +0.6V is present on its base. Similarly, Q5 turns on if a DC signal of more than –0.6V is present on its emitter. This in turn pulls transistor Q6's base low and so Q6 also turns on.

Normally, in the absence of amplifier faults, transistors Q5-Q7 are all *off* and Q3 is biased *on* via the 100kΩ resistor connected between its base and the positive supply rail (ignore Q1

Table 1: Resistor Colour Codes

❑	No.	Value	4-Band Code (1%)	5-Band Code (1%)
❑	2	100kΩ	brown black yellow brown	brown black black orange brown
❑	2	33kΩ	orange orange orange brown	orange orange black red brown
❑	4	22kΩ	red red orange brown	red red black red brown
❑	2	22kΩ 1W, 5%	red red orange gold	not applicable
❑	2	10kΩ	brown black orange brown	brown black black red brown
❑	1	2.7kΩ	red violet red brown	red violet black brown brown
❑	2	100Ω	brown black brown brown	brown black black black brown
❑	1	10Ω	brown black black brown	brown black black gold brown



This prototype board (also shown in the other photos) used an MJE350 transistor for Q4, but this has now been changed to a BC556.

and Q2 for the time being). As a result, Q3 pulls Q4's base down (via resistor R1) to just over 12.6V, as set by diode D4 and Zener diode ZD1, and so Q4 and relay RLY1 are also on.

Now let's consider what happens if an amplifier fault condition results in DC being present at its output. In this case, either Q6 or Q7 turns on and pulls Q3's base low via a 10Ω resistor. When that happens, Q3, Q4 and the relay all immediately turn off, disconnecting the speakers.

Diode D5 protects Q4 by quenching any back-EMF spikes that are generated when the relay is switched off.

Transistors Q8, Q9 and Q10 monitor the left channel of the amplifier and they switch Q3, Q4 and the relay in exactly the same manner.

Relay specifications

The relay selected for the job is a 24V DPDT (double-pole, double-throw) type, with contacts rated at 10A. There are two reasons for this high contact rating. First, we want the contact resistance in the relay to be as low as possible so that it has negligible effect on the amplifier's performance, as regards to distortion, damping factor and so on.

Second, the relay contacts have to pass and break the heavy DC current which would otherwise flow through the loudspeaker if a fault occurs in the amplifier. However, we don't merely use the relay to disconnect the amplifier's output from the speakers. If we simply did this, it's possible that the contacts would just arc across and so the heavy DC current would continue to flow through the loudspeaker.

That might seem unlikely, but when you have a heavy DC current and a high DC voltage pushing it along, it can be quite hard to break the circuit. This problem is solved by shorting the moving (pole) relay contacts to the loudspeaker ground lines (via the otherwise unused NC contacts) when the relays turn off. This diverts the arc current to chassis and ensures that the fuses blow on the amplifier.

By the way, the relay specified in the parts list (Altronics S-4313 – **www.altronics.com**) has an in-built green LED that lights when the relay turns on. It's a nice feature that lets you quickly check the status of the relay during testing, but it is not really necessary.

Muting delay at switch-on

Muting at switch-on is achieved using a delay circuit. This consists of the 100kΩ resistor and the 47µF capacitor connected to Q3's base, along with diode D4 and Zener diode ZD1.

When power is first applied, the 47µF capacitor is discharged and Q3's base is held low. As a result, Q3, Q4 and the relay all remain off. The 47µF capacitor then charges via the 100kΩ resistor until, after about five seconds, it reaches 13.2V. This now forward biases Q3, which then turns on Q4 and the relay to connect the loudspeakers. This is more than sufficient time for the amplifier modules to settle down and achieve stable operating conditions.

Why 13.2V on Q3's base? Well, that's the sum of the voltages across ZD1, diode D4 and Q3's base-emitter junction when the transistor is on.

Switch-off muting

Transistors Q1 and Q2, together with diodes D2 and D3, provide the switch-off muting function.

Diodes D2 and D3 rectify the AC voltage that's fed to the AC Sense input (at connector CON2) from a transformer secondary winding (up to 50V AC max). Provided this AC input voltage is present, the rectified output forward biases transistor Q1 and so keeps it turned on. This in turn holds Q2's base low and so Q2 is off and Q3 functions normally.

The 100kΩ resistor and the 470nF capacitor, at Q2's base, form a time constant that's long enough to ensure the Q2 remains off when Q1 very briefly turns off during the AC zero crossing points.

However, if the AC signal ceases (ie, at switch off), Q1 immediately turns off and Q2 turns on and quickly discharges (within a millisecond or so) the 47µF timing capacitor via a 100Ω resistor. As a result, Q3, Q4 and the relay all turn off and the loudspeakers are disconnected, effectively eliminating any switch-off thumps.

Over-temperature input

Connector CON3 is the temperature sensor input. It relies on the use of a normally-open (NO) thermal switch that's normally bolted to the heatsink used for the amplifier's output power transistors.

Basically, this input is wired in parallel with transistors Q6 and Q7 (and Q9 and Q10) and it controls transistor Q3 in exactly the same manner.

When the temperature reaches a preset level (set by the switch itself), the contacts inside the thermal switch close and pull Q3's base low via the associated 10Ω resistor. As a result, Q3 turns off and this switches off Q4 and the relay.

Parts List – Speaker Protection Module

- 1 PC board, code 693, available from the *EPE PCB Service*, size 112.5mm × 80mm
- 1 10A 24V DPDT PC-mount relay (Altronics S-4313)
- 3 2-way 5mm or 5.08mm pitch terminal blocks (CON1 to CON3)
- 4 M3 × 10mm tapped spacers
- 4 M3 × 6mm pan head screws
- 6 M4 × 10mm pan head screws
- 6 M4 flat washers
- 6 M4 shakeproof washers
- 6 M4 nuts
- 6 6.3mm double-ended 45° or 90° chassis-mount spade lugs
- 0.7mm diameter tinned copper wire for link

Semiconductors
- 7 BC546 *NPN* transistors (Q1-Q3, Q5, Q7,Q8 and Q10)
- 3 BC556 *PNP* transistors (Q4, Q6 and Q9)
- 4 1N4004 diodes (D1 to D3, D5)
- 1 1N4148 diode (D4)
- 1 12V 1W Zener diode (ZD1)

Capacitors
- 1 47µF 63V PC electrolytic
- 4 47µF 50V non-polarised (bipolar) electrolytics
- 1 470nF 50V metallised polyester (MKT)

Resistors (0.25W 1% carbon film)

2 100kΩ	1 10kΩ 0.5W
2 33kΩ	1 2.7kΩ (R1)
4 22kΩ	2 100Ω
1 10kΩ	1 10Ω
2 22kΩ 1W 5%	R2 See Text

Attaching The Spade Connectors

It's important that the double-ended spade lugs are fitted correctly to the PC board.

Fig.3 (right) shows how they are mounted. Each lug is secured using an M4 x 10mm screw, a flat washer (which goes against the PC board pad), an M4 star lockwasher and an M4 nut.

The trick to installing them is to first do the nut up finger-tight, then rotate the assembly so that it is at a right-angle to the PC board. A screwdriver is then used to hold the M4 screw and the spade lug stationary while the nut is tightened from below using an M4 socket and ratchet.

Do the nut up nice and tight to ensure a good connection and to ensure that the assembly does not rotate. Don't be too heavy-handed though, otherwise you could crack the PC board.

The exact same mounting method should also be used for the spade lug terminals attached to the power amplifier modules and to the power supply board described last month.

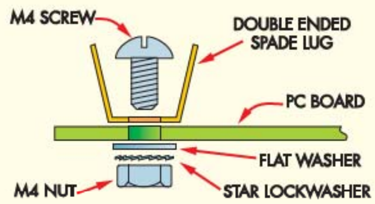


Fig.3

When the heatsink subsequently cools down, the thermal cutout opens again and Q3, Q4 and the relay turn on again to reconnect the loudspeakers.

As previously stated, the over-temperature sense feature is not used with the Class-A Stereo Amplifier because the heatsinks run hot all the time and disconnecting the loudspeakers does nothing to cool them.

Power supply

Power for the Loudspeaker Protection circuit is derived from a suitable DC rail within the amplifier. This can range anywhere from about 20V DC up to 70V DC.

In the case of the Class-A Stereo Amplifier, we use the +22V and 0V rails from the power supply board. The 'AC Sense' signal is picked up directly from the AC terminals on the bridge rectifier (more on this in a future issue).

Note that the values shown for R1 and R2 on Figs 1 and 2 assume a 22V to 24V supply rail. If the available DC supply rail is higher than this, then resistors R1 and R2 must be changed accordingly to ensure a base current of about 3 to 5mA for Q4 (as set by R1) and to ensure that no more than about 24V DC is applied to the relay coil (R2). In the latter case, it's just a matter of selecting R2 so that the relay current is about 37mA (assuming that the relay has a coil resistance of about 650Ω).

The inset table included with Fig.1 shows resistor values to suit differing supply rails.

Construction

The parts for the Speaker Protection and Muting Module are all mounted on a PC board, coded 693. This board is available from the *EPE PCB Service*. Fig.2 shows the component layout and assembly details.

Mount the resistors and diodes first, taking care to ensure that the diodes are all oriented correctly. Table 1 shows the resistor colour codes, but you should also check each resistor using a digital multimeter before installing it, just to be sure.

Install a 2.7kΩ 0.25W resistor for R1 and a link for R2 if you are building the unit for the Stereo Class-A Amplifier. Alternatively, select these resistors from the inset table shown in Fig.1 if you intend using a supply rail greater than 24V.

If the supply rail is between the values shown in the table, then simply scale the resistor values accordingly and use the nearest preferred value.

The six double-ended spade lugs for the speaker input and output terminals are next on the list. These are attached using M4 × 10mm screws, flat washers, star washers and nuts – see Fig.3.

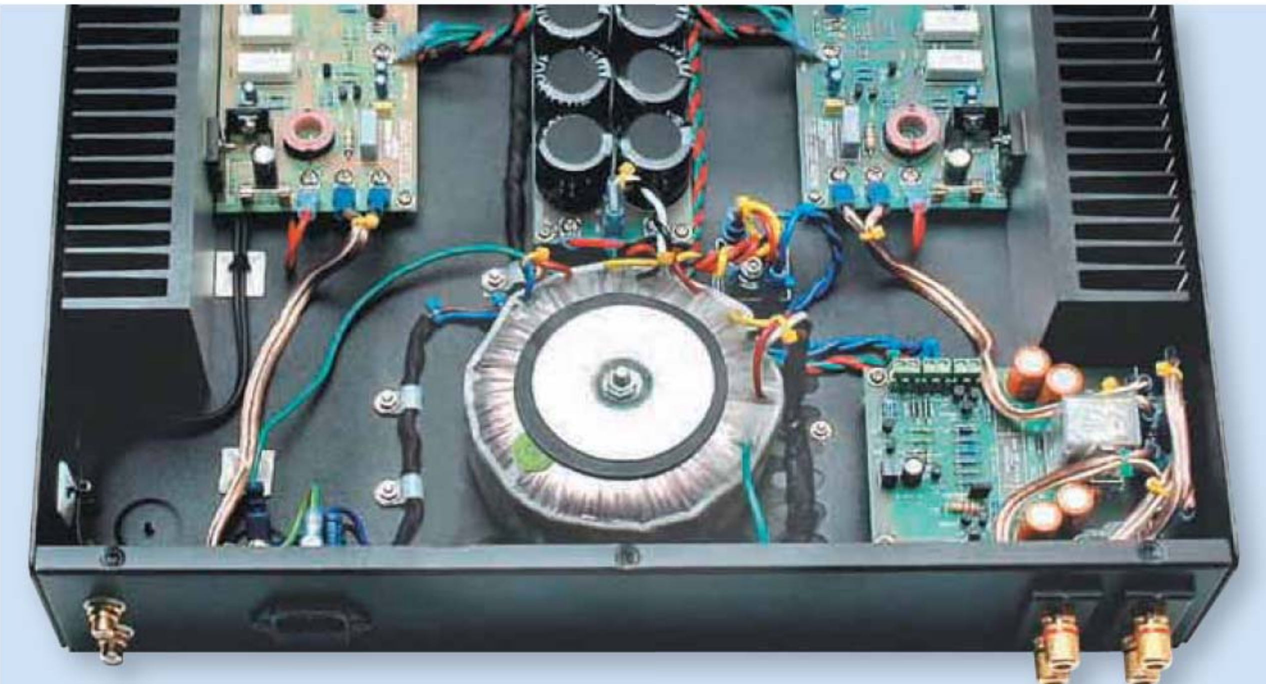
Note that, ideally, the double-ended spade lugs supplied should be 90° types. However, if you are supplied with 45° types, just bend the lugs to 90° before installing them on the board.

The transistors, the electrolytic capacitor and the bipolar capacitors can now be installed, taking care to ensure that the correct transistor type is fitted to each location. The four 47µF bipolar capacitors can go in either way around, but do watch the orientation of the polarised 47µF 63V electrolytic capacitor.

Finally, you can complete the board assembly by fitting the three 2-way terminal blocks and the DPDT relay.

Testing

If you have a suitable DC supply you can test the unit prior to installing it. To do this, first connect the supply to screw terminal block CON1 and install a wire link between one of the CON2 AC Sense input terminals and the positive supply rail (this is done to ensure transistor Q1 turns on). Do *not* connect anything to



This rear view shows the Loudspeaker Protection Module installed in the 20W Class-A Stereo Amplifier (bottom right).

the temperature switch input or to the speaker terminals at this stage.

Next, apply power and check that the relay turns on after about five seconds. If it does, temporarily short the temperature switch input – the relay should immediately switch off.

Similarly, the relay should immediately switch off if you disconnect the link to the AC Sense input.

The next step is to check that the relay switches off if a DC voltage is applied to the loudspeaker terminals (this simulates an amplifier fault condition). To do this, apply power, wait until the relay switches on, then connect a 3V (2 × 1.5V cells in series) or 9V battery (either way around) between the ground terminal of CON1 and the LSPKIN+ terminal. The relay should immediately switch off.

Repeat this test for the RSPKIN+ terminal, now reverse the battery polarity and perform the above two tests again. The relay should switch off each time the battery is connected.

Note that we don't connect to the LSPKIN– or RSPKIN– terminal for this test because these two inputs are fully floating at this stage. That changes when the module is installed in a chassis and the loudspeaker leads are connected, because the negative loudspeaker terminals on the amplifier are connected to chassis (via the power supply).

Troubleshooting

If the relay doesn't activate when power is first applied, switch off immediately and check for wiring errors – eg, incorrect supply polarity, or a transistor in the wrong location. If this doesn't locate the fault, switch on and check the supply voltage, then check the voltages around the transistors. Q3's emitter should be at about 12.6V and its collector at 12.8V, while both Q3 and Q4 should have base-emitter voltages of 0.6V.

Similarly, Q1 should have a base-emitter voltage of 0.6V (provided the link between the AC Sense input and the positive supply terminal is in place) but the other transistors (Q2 and Q5 to Q10) should all be off – ie, they should have base-emitter voltages of 0.2V or less.

If Q3's base voltage is low (around 0.2V), then it could mean that Q2 is on and Q1 is off, possibly due to no voltage being applied to Q1's base. Alternatively, one of the transistors in the speaker input monitoring circuits (ie, Q5 to Q10) could be faulty (short circuit). You can quickly isolate which circuit section is at fault by disconnecting the 10Ω and 100Ω resistors to Q3's base.

Just remember that all transistors that are turned on will have a base-emitter voltage of about 0.6V. This should enable you to quickly locate where the trouble lies.

That's all for now. Next month, we'll describe the low-noise Preamplifier and Remote Volume Control Module. ***EPE***

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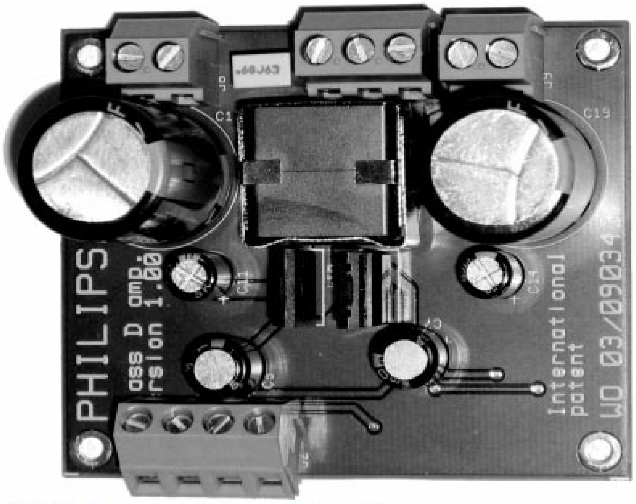
Temperature Sensors

Temperature sensors are variously called 'thermostat switches', 'thermal cutouts' and 'thermal circuit breakers' and are available in a range of trip temperatures from 50 to 100°C. Note that the temperature sensor used with this unit must be a normally open (NO) type.



High power, high quality discrete Class D amplifier

The Universal Class D (UcD) version 1.00 demonstrator board implements a 200 W true RMS (into a 4 W load) high quality audio power amplifier on a very compact printed-circuit board. The amplifier is built-up of discrete components only.

The Class D concept allows efficient and cost-effective high output power audio amplifiers to be created. The Universal Class D (UcD) principle enables PWM amplifiers to perform at an excellent sonic level while making use of a relatively simple closed-loop topology.

200W demo amplifier specifications

Property	Condition	Value
Output power	Supply voltage = ± 45V R_{load} = 4Ω	200W (RMS)
Efficiency	P_{out} = 100W R_{load} = 4Ω	≥ 92%
THD + N	P_{out} = 10W 20Hz < f < 20kHz	≤ 0.03%
SNR		≥ 120dB

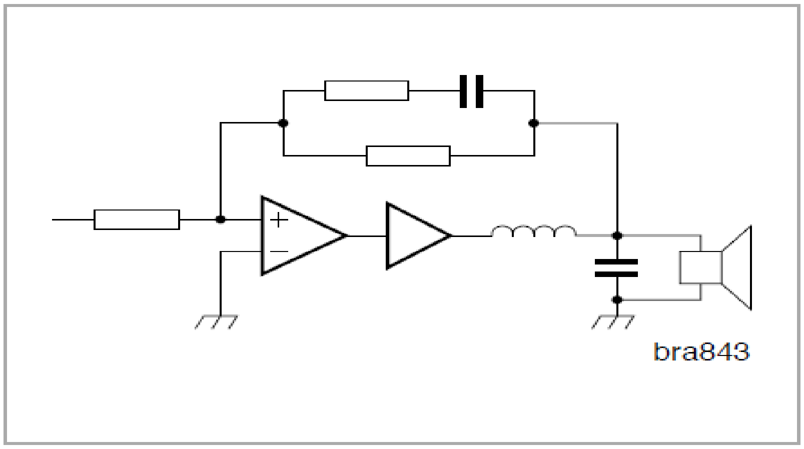


Fig.1 UcD principle diagram

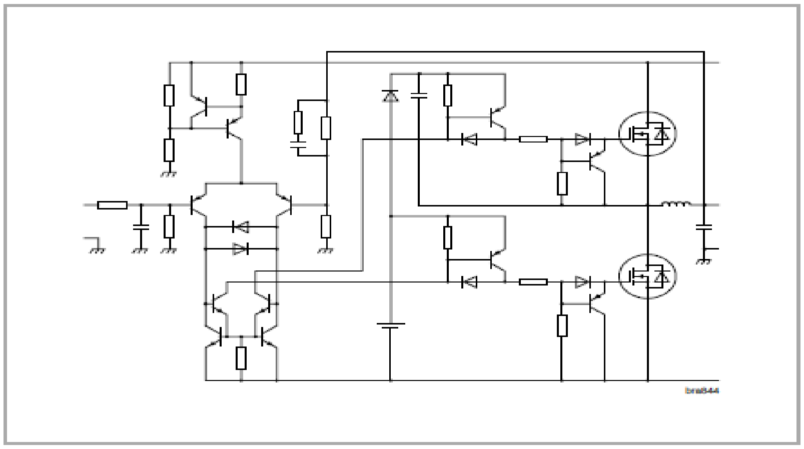
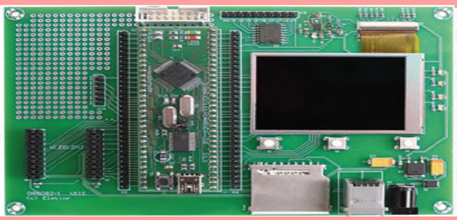
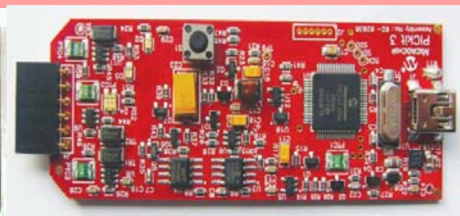


Fig. 2 Basic discrete UcD implementation

For detail technical specifications of this discrete design, please visit:
http://www.handsontec.com





Stereo Class-A Amplifier Pt.4

By JOHN CLARKE & GREG SWAIN

Preamplifier & Remote Volume Control Module

In Part 4 this month, we present a high-performance Stereo Preamplifier & Remote Volume Control module. It's a low-noise, low-distortion design, specifically engineered for the Class-A amplifier, but it can also be used with other stereo power amplifiers.

DEPENDING on your requirements, you have several options when it comes to using the new Class-A Stereo Amplifier. Basically, the unit can be combined with a high-quality external preamplifier or used as a stand-alone unit.

Typically, an external preamplifier will be necessary if you want to connect several signal sources and switch between them; eg, select between a CD player, DVD player and a tuner. The Class-A Stereo Amplifier would then function simply as a power amplifier, with the signal from the external preamp fed directly to the inputs of the power amplifier modules. In this case, all you would need to build into the chassis are the left and right-channel Class-A Power Amplifier modules (Oct'08 and Nov'08), plus the Loudspeaker Protector & Muting Module (Dec'08).

If you do elect to use an external preamplifier, then the Studio Series Stereo Preamplifier (Feb'08) makes the ideal companion unit. The Studio Preamplifier is an excellent performer that's quite up to the job (especially considering its distortion is typically less than 0.0005%).

Preamplifier features and performance

Main features

- High performance design – very low noise and distortion
- Designed for the Class-A Stereo Amplifier, (Oct, Nov'08) but can also be used with other power amplifier modules
- On-board remote volume control circuit with motorised potentiometer and muting

Measured performance

Frequency response....................flat from 10Hz to 20kHz, –3dB @ 100kHz
Input impedance .... ~22kΩ
Output impedance.. 100Ω
Harmonic distortion....................................typically <0.0005%
Signal-to-noise ratio.............–125dB unweighted for 1V input
Channel crosstalk...typically –125dB

Volume control

Alternatively, many readers will want to use only one signal source, typically a CD or DVD player. In that case, the Class-A Stereo Amplifier can be used as a standalone unit, but you do need to add a volume control. If your CD player is already fitted with an output level control, you may be tempted to dispense with a volume control on the amplifier, but that could be a mistake.

Just imagine what a blast you will get from the amplifier and loudspeakers if you turn on the CD player and it has been inadvertently set to full output level. The result would not only be deafening, but it could easily blow your tweeters.

The simplest solution that we would recommend is to feed the signal in via a dual-ganged (stereo) 10kΩ *log* pot and we'll show you how to do that next month, when we bring all the modules together into a single unit, if you want to use that option. This simple scheme does have its problems though. First, the input signal level may be insufficient to drive the amplifiers to full power output, even when using a CD player. The amplifier modules have an input sensitivity of 625mV for full power, but some recordings may give average output signal levels well below this.

Second, using a simple volume control varies the input impedance to the power amplifiers, thereby slightly degrading the signal-to-noise ratio. Admittedly, we're splitting hairs somewhat here – but after all, this is a true audiophile's amplifier.

Preamplifier module

So how do you eliminate those problems and achieve the level of performance we want? The answer is to incorporate a high-quality preamplifier module into the Class-A Stereo Amplifier chassis. This will result in an attractive self-contained package that we think will appeal to many people – particularly those who just want to use a single CD/DVD player.

The preamplifier module described here meets the above criteria. It's a minimalist design, which delivers ultra-low noise and distortion, but with more than enough gain (with the 'wick' wound right up) to drive the 20W Class-A Amplifier modules to full power output. In fact, if you were to wind it up too far, the amplifier will be driven well into clipping and horrible distortion.

That pretty much defeats the purpose of building a high quality amplifier, so don't do it!

This preamplifier is a two-chip design, employing a dual op amp IC in each channel, the first stage providing the gain and the second stage acting as a buffer for the volume control, to present a constant low output impedance to the power amplifier modules.

Low-noise op amps

The original Studio Series Preamplifier mentioned earlier was based on the high-performance OPA2134 op amps from Burr-Brown. These are specified at an extremely low 0.00008% harmonic distortion at 1kHz and the harmonic distortion (THD) for the completed preamplifier was typically less than 0.0005%.

This time we've gone one better and specified the National Semiconductor LM4562 dual op amp. This fairly new device is specified at just 0.00003% harmonic distortion at 1kHz, which is even lower than for the OPA2134. In fact, it is far below the measurement capability of most commercially available test equipment.

As a result, the performance of the module on its own is actually far better than the completed stereo amplifier. Just running with its own regulated supplies (and not connected to the amplifier), the preamplifier module delivers a harmonic distortion figure that's typically less than 0.0005%. Furthermore, its signal-to-noise ratio with respect to a 1V input signal is around –125dB unweighted (22Hz to 22kHz bandwidth) and separation between channels is also around –125dB.

Ultimately, it is not possible to get this fantastic performance from the completed stereo amplifier. And why not? The main reason is that residual noise and hum from the power supply degrades the overall measured result, even though the finished amplifier is extremely quiet.

Would it be possible to get a better measured distortion performance? The answer is a qualified yes, provided we had completely separate power supplies for both channels. The same comment applies to channel separation and residual noise. Such a solution would be a lot more expensive and would probably

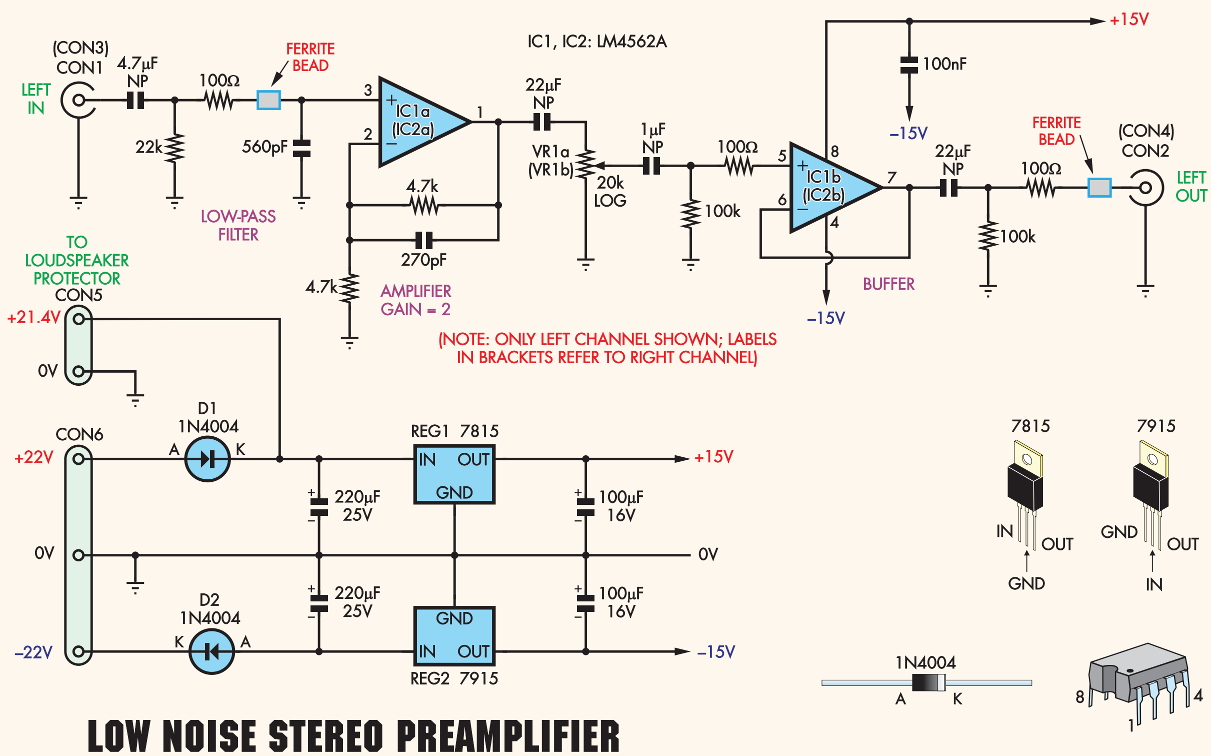


Fig.1: each channel of the preamp is based on a low-distortion LM4562A dual op amp (left channel only shown). IC1a has a gain of two while IC1b functions as a unity gain buffer to provide a constant low-impedance output.

involve two separate power amplifiers – the so-called 'mono block' solution.

By the way, there's no source selection built into the preamplifier, as we're assuming that you will be using it with just a single source. If you do want to switch between different sources, then you will need to use an external switch box (or an external preamp, as indicated earlier).

Remote volume control

OK, we just couldn't help ourselves – we just had to include remote volume control as part of the preamp design. After all, no sound system is complete these days without remote volume control and this one has all the 'must-have' features.

By using the recently-released PIC16F88-I/P chip, as opposed to the PIC16F84 used in an earlier design, we've been able to eliminate an LM393 comparator IC and a low-voltage reset circuit.

The remote Volume Control section uses a motorised potentiometer. Press the 'Volume Up' and 'Volume Down' buttons on your remote control and the pot rotates clockwise and anticlockwise. It takes about nine seconds for the pot to travel from one end to the other using these controls.

For finer adjustment, the 'Channel Up' and 'Channel Down' buttons can be used instead. These cause the pot shaft to rotate only about 1° each time one of these buttons is pressed. Alternatively, holding one of these buttons down rotates the pot from one end to the other in about 28 seconds.

If any button is held down when the pot reaches an end stop, a friction clutch in the motor's gearbox slips so that no damage is done.

Automatic muting is another handy feature. Press the 'Mute' button on the remote and the pot automatically rotates to its minimum position and the motor stops. Hit the button again and it returns to its original position. Don't want the pot to return all the way to its original setting? Easy – just hit one of the volume control buttons when the volume reaches the desired level.

A couple of LED indicators – 'Ack' and 'Mute' – are used to indicate the status of the Remote Volume Control. The blue Ack (acknowledge) LED flashes whenever an infrared signal is being received from the remote, while the orange Mute LED flashes while the muting operation is in progress and then remains on when the pot reaches its minimum setting.

So how does the unit remember its original setting during muting? Well, the microcontroller actually measures the time it takes the pot to reach its minimum setting. Then, when the Mute button is pressed again to restore the volume, power is applied to the motor drive for the same amount of time.

Preamplifier circuit details

OK, so much for the background stuff. Let's see how it all works, starting with the audio preamplifier.

Fig.1 shows the circuit details, with just the left channel preamp stages shown for clarity, along with the power supply. The right channel preamp circuitry is identical to the left.

The audio signal from the source is AC-coupled to the input of the first op amp (IC1a) via a 4.7µF capacitor, while a 22kΩ resistor to ground provides input termination. In addition, the signal passes via a low-pass filter formed by a 100Ω resistor, a ferrite bead and a 560pF capacitor. This attenuates radio frequencies (RF) ahead of the op amp input.

IC1a operates with a voltage gain of two (+6dB) by virtue of the 4.7kΩ feedback resistors. The 4.7kΩ resistor and 270pF capacitor combination roll off the top end frequency response, with a –3dB point at about 150kHz. This gives a flat response over the audio spectrum, while eliminating the possibility of high-frequency instability.

Note, however, that the –3dB high-frequency point for the entire amplifier is about 100kHz – see Fig.3.

The output from IC1a (pin 1) drives one end of potentiometer VR1a (20kΩ) via a 22µF non-polarised coupling capacitor. The pot acts as a simple voltage divider and the signal on its wiper is fed to the input (pin 5) of op amp IC1b, via a 100Ω resistor.

The wiper of the pot is also AC-coupled, this time using a 1µF non-polarised capacitor. This is done to prevent any DC voltage appearing across the pot, which if present would cause an irritating sound during wiper movement.

IC1b is used as a unity-gain buffer. This stage allows the preamp to provide a low-impedance output regardless of volume control setting. A 22µF non-polarised capacitor couples the audio signal to the output via a 100Ω resistor, which is included to ensure stability when driving the cable and amplifier input capacitance. This resistor, together with the ferrite bead in series with the output, also helps to attenuate RF noise that might otherwise find its way back into the preamp circuit.

Power supply

Power for the circuit is derived directly from the ±22V terminals on the power supply board (described in Nov'08). Diodes D1 and D2 provide reverse polarity protection, after which each rail is further filtered using a 220µF electrolytic capacitor. Two 3-terminal voltage regulators – REG1 and REG2 – then provide ±15V supply rails to power the op amps.

In addition, +22V and 0V outputs are provided from the power supply (via a separate terminal block – CON5). These outputs are used to power last month's Loudspeaker Protector and Muting Module when the amplifier is finally assembled.

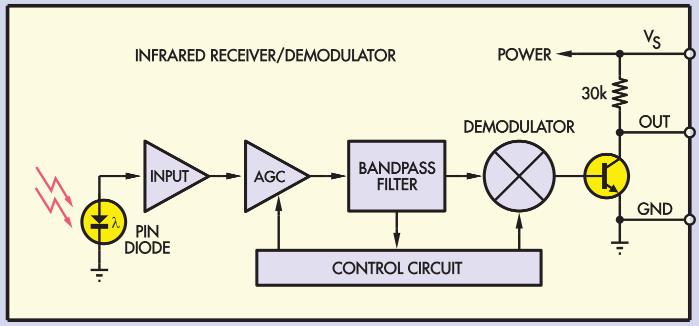


Fig.2: the IR receiver module used in the Remote Volume Control circuit contains a lot more than just a photo diode. This block diagram of the internals reveals an amplifier plus discrimination and demodulation circuits, all in the 3-pin package. After the 38kHz carrier is removed, the data appears on the 'OUT' pin (1) ready to be processed by the micro.

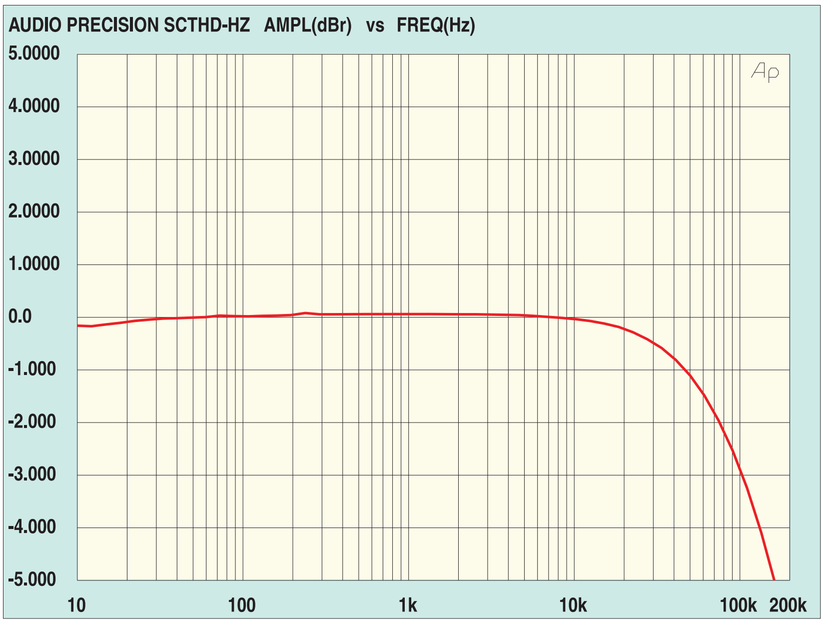


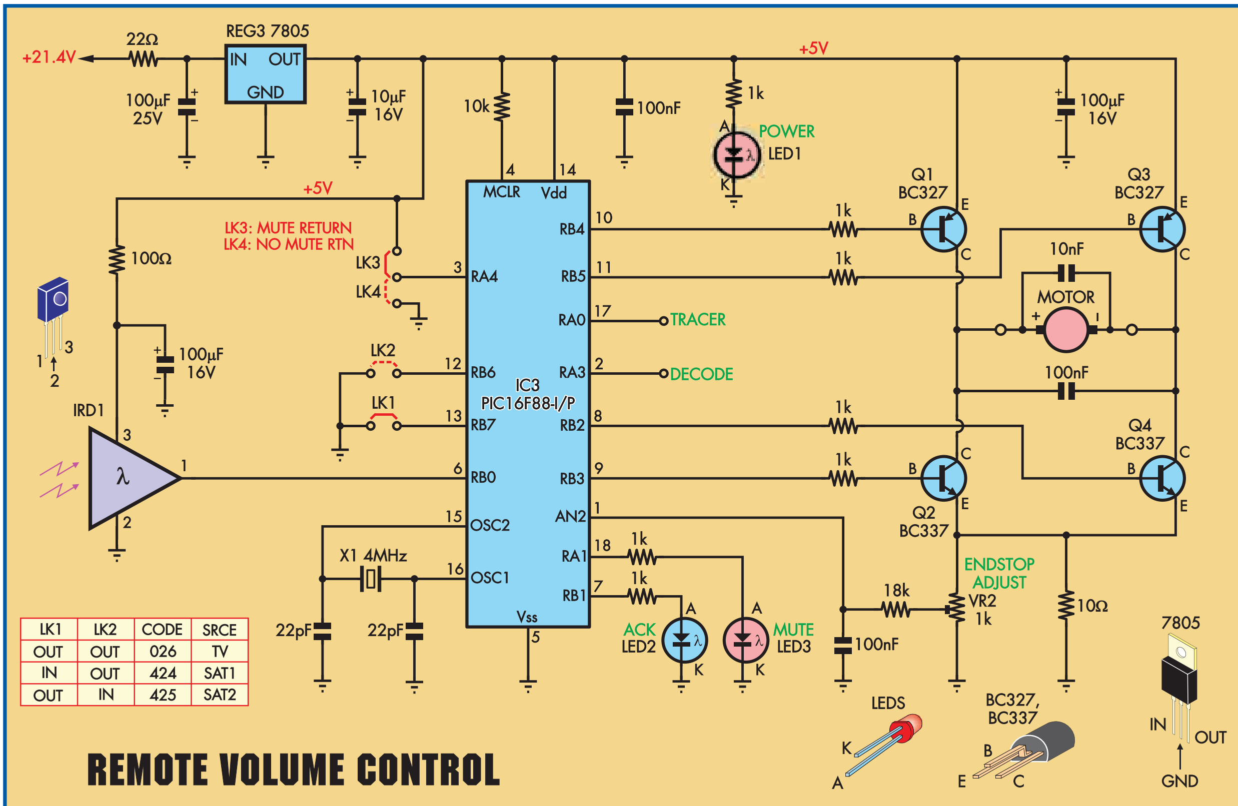
Fig.3: this graph shows the frequency response of the whole amplifier (including the preamplifier), taken at a power level of 1W into 8Ω. It's almost ruler flat from 10Hz to 20kHz and then rolls off gently to be –3dB down at about 100kHz.

Remote volume control circuit

Now let's take a look at the circuit for the Remote Volume Control – see Fig.4. The three critical components are the PIC16F88-I/P microcontroller (IC3), the motorised potentiometer and an infrared receiver/detector module (IRD1).

In operation, the microcontroller monitors the demodulated infrared signal from IRD1. It then decodes this signal and drives the pot motor according to the RC5 code (see panel) sent by the handheld remote.

Sensor IRD1 only has three leads, but it is not a simple device; in reality,



LK1	LK2	CODE	SRCE
OUT	OUT	026	TV
IN	OUT	424	SAT1
OUT	IN	425	SAT2

Fig.4: the Remote Volume Control section is based on a PIC16F88-I/P microcontroller (IC3). This processes the signal from infrared detector IRD1 and controls the pot motor via H-bridge transistors Q1 to Q4.

it is a complete infrared detector and processor – see Fig.2. First, it picks up the 38kHz infrared pulse signal from the remote control and amplifies this to a constant level. This is then fed to a 38kHz bandpass filter and then demodulated to produce a serial data burst at IRD1's pin 1 output.

From there, the demodulated signal from IRD1 is fed into IC3's RB0 input (pin 6). Operating under program control, the microcontroller then reconstitutes the demodulated data into byte-wide format using the Philips RC5 protocol specification.

Basically, the Remote Volume Control can be operated on one of three modes within the RC5 Code. These are TV1, SAT1 and SAT2 and the desired code is selected using jumper links LK1 and LK2 at the RB7 and RB6 inputs of IC3.

Normally, both these inputs are pulled high via internal resistors in IC3, but they can be pulled low using links LK1 and LK2. In operation, IC3 monitors these inputs and compares the selected code with the incoming serial data from IRD1. If the detected code is correct, the motorised potentiometer will be driven according to the pushbutton command sent by the remote control.

Motor drive

The motorised potentiometer (VR1) is driven by four transistors (Q1 to Q4) arranged in an H-bridge configuration. These in turn are driven via the RB2 to RB5 outputs of IC3 via 1kΩ resistors.

The motor is off when the RB2 to RB5 outputs are all set high. Ports RB4 and RB5 turn *PNP* transistors Q1 and Q3 off, while RB2 and RB3 turn *NPN* transistors Q2 and Q4 on. As a result, both terminals of the motor are pulled low and so the motor is off. Note that the emitters of Q2 and Q4 both connect to ground via a common 10Ω resistor (more on this shortly).

The transistors operate in pairs so that the motor can be driven in either direction (to increase or decrease the volume). To drive potentiometer VR1 clockwise, port RB3 goes low and turns off transistor Q2, while RB4 goes low and turns on Q1. This means that the lefthand terminal of the motor is taken to +5V via transistor Q1, while the righthand terminal of the motor is held low via Q4. As a result, current flows through Q1, through the motor and then via Q4 and the 10Ω resistor to ground.

Conversely, to spin the motor in the other direction, transistors Q1 and Q4 are switched off and Q2 and Q3 are switched on. As a result, the righthand motor terminal is pulled to +5V via Q3, while the lefthand terminal is pulled low via Q2.

The voltage across the motor depends on the voltage across the common 10Ω emitter resistor and that in turn depends on the current. Typically, the motor draws about 40mA when driving potentiometer VR1, but this rises to over 50mA when the clutch is slipping. As a result, the motor voltage is around 4.5V to 4.6V due to the 0.4 to 0.5V drop across the 10Ω resistor (the rated motor voltage is 4.5V).

Current sensing and muting

Once the pot's wiper reaches its fully clockwise or anti-clockwise position, a friction-type clutch in the gearbox begins to slip. This prevents the motor from stalling, while also allowing the user to manually rotate the pot shaft if necessary.

The muting function depends on the microcontroller's ability to detect when the wiper is 'on the stops'. It does this by indirectly detecting the increase in the motor current.

In operation, preset VR2 samples the voltage across the 10Ω resistor when the motor is running. The resulting signal at its wiper is then filtered using an 18kΩ resistor and a 100nF capacitor (to remove the commutator hash from the motor) and applied to IC3's analogue AN2 input (pin 1).

This analogue input is measured (by IC3) to a resolution of 10-bits, or about 5mV. Provided this input is below 200mV, the PIC microcontroller allows the motor to run. However, as soon as the voltage rises above this 200mV limit, the motor is stopped.

When the motor is running normally, the current through it is about 40mA which produces 0.4V across the 10Ω resistor. Trimpot VR2 is used to attenuate this voltage and is adjusted so that the voltage at AN2 is slightly below the 200mV limit.

When the motor reaches the end of its travel, the extra load imposed by the slipping clutch increases the current and the voltage applied to the AN2 input rises above 200mV. This is detected by IC3 during muting and the microcontroller then switches the H-bridge transistors (Q1 to Q4) accordingly, to immediately stop the motor.

Note that AN2 is monitored only during the Muting operation. At other times, when the volume is being set by the Up or Down buttons on the remote control, the voltage at AN2 is not monitored. As a result, the clutch in the motor's gearbox assembly simply slips when potentiometer VR1 reaches its clockwise or anticlockwise limits.

Pressing the Mute button on the remote again after muting returns the volume control to its original setting. This is the 'Mute Return' feature referred to earlier.

Note also that connecting IC3's RA4 input to ground via link LK4 disables this feature. Conversely, to enable Mute Return, link LK3 is used to pull RA4 to +5V.

Indicator LEDs

LEDs 1 to 3 indicate the status of the circuit. The red Power LED (LED1) lights whenever power is applied to the circuit and provides power on/off indication for the entire amplifier.

The other two LEDs – Ack (acknowledge) and Mute – light when their respective RB1 and RA1 outputs are pulled high (to +5V). As explained previously, the Ack LED flashes whenever the RB0 input receives an infrared signal from the remote control, while the Mute LED flashes during the Mute operation and then stays lit while the volume remains muted.

Crystal oscillator

Pins 15 and 16 of IC3 are the oscillator inputs for the 4MHz crystal X1, which is used to provide the clock signal. This oscillator runs when the circuit is first powered up for about 1.5 seconds. It also runs whenever an infrared signal (IR) is received at RB0 and then for a further 1.5 seconds after the last receipt of a signal, after which the oscillator shuts down.

Note, however, that this shut down does not occur if a Muting operation is still in process.

Shutting down the oscillator in the absence of an infrared signal from the remote control ensures that no noise is radiated into sensitive audio circuitry when the volume control is not being altered.

Waking up again

As just stated, when there is no IR signal from the remote, the circuit goes to 'sleep' (ie, the oscillator shuts down)

Parts List – Preamp & Remote Volume Control

1 PC board, code 696, available from the *EPE PCB Service*, size 201 × 63mm
1 Alpha dual-ganged 20kΩ log motorised pot (VR1) (Altronics Cat. R2000)
1 1kΩ (code 102) horizontal trimpot (VR2)
1 DIP 18-pin IC socket
2 DIP 8-pin IC sockets
5 2-way PC-mount screw terminal blocks, 5.08mm spacing (Altronics Cat. P2034A – **do not substitute**)
1 3-way PC-mount screw terminal block, 5.08mm spacing (Altronics Cat. P2035A – **do not substitute**)
1 4MHz crystal (X1)
4 ferrite beads (Altronics Cat. L5250A)
1 3-way SIL pin header, 2.54mm spacing
1 2-way SIL pin header, 2.54mm spacing
1 2-way DIL pin header, 2.54mm spacing
2 jumper links to suit headers
1 6.35mm panel-mount single-ended spade connector
1 6.35mm spade connector
4 M3 x 25mm tapped standoffs
4 M3 x 6mm screws
1 M4 x 10mm screw
1 M4 nut
1 M4 flat washer
1 M4 star washer
1 250mm length of 0.8mm tinned copper wire
1 150mm length of red hook-up wire
1 150mm length of black hook-up wire
2 100mm cable ties

Semiconductors
2 LM4562 op amps (IC1, IC2)
1 PIC16F88-I/P programmed with 'Low Noise Preamp Volume.hex' (IC3)
1 infrared decoder (IRD1)
1 7815 +15V regulator (REG1)
1 7915 – 15V regulator (REG2)
1 7805 +5V regulator (REG3)
2 BC327 PNP transistors (Q1,Q3)
2 BC337 NPN transistors (Q2,Q4)
1 3mm red LED (LED1)
1 3mm blue LED (LED2)
1 3mm orange LED (LED3)

Capacitors
2 220µF 25V PC electrolytic
1 100µF 25V PC electrolytic
4 100µF 16V PC electrolytic
4 22µF NP electrolytic
1 10µF 16V PC electrolytic
2 4.7µF NP electrolytic
2 1µF NP electrolytic or MKT polyester
5 100nF MKT polyester
1 10nF MKT polyester
2 560pF ceramic
2 270pF ceramic
2 22pF ceramic

Resistors (0.25W 1% carbon film)

4 100kΩ	7 1kΩ
2 22kΩ	7 100Ω
1 18kΩ	1 22Ω
1 10kΩ	1 10Ω
4 4.7kΩ	

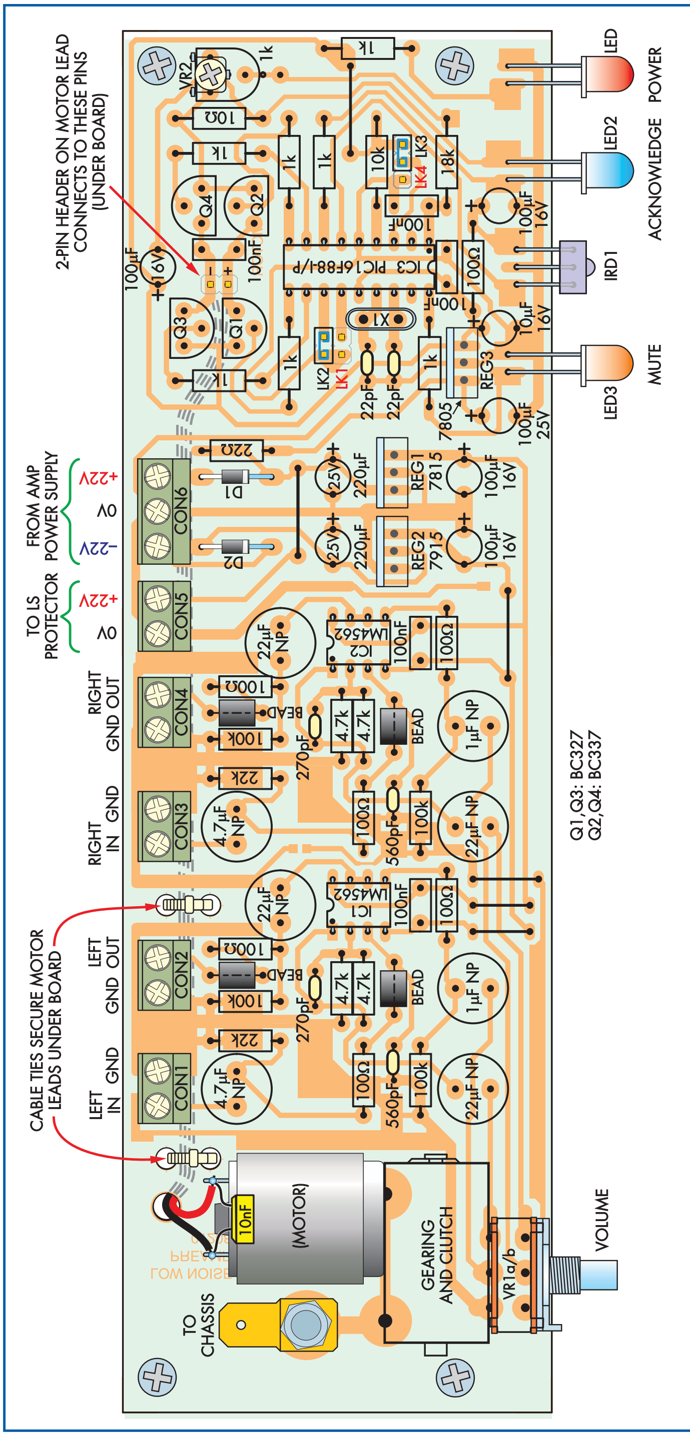


Fig.5: follow this parts layout diagram to build the Preamplifier & Remote Volume Control board. Be sure to use the correct part at each location and take care with components that are polarised. The leads to the motor are strapped to the underside of the board using cable ties.

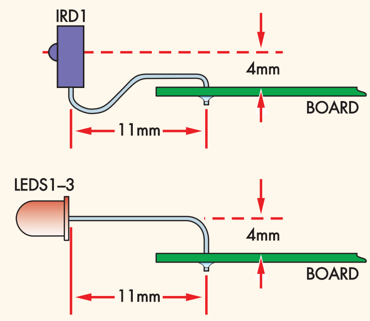


Fig.6: bend the leads for IRD1 and the three LEDs as shown here before installing them on the PC board. The centre line of each lens must be 4mm above the board surface.

and so no noise is produced. However, as soon as it receives an IR signal, the circuit 'wakes up' and drives potentiometer VR1. It then shuts down after about 1.5 seconds if it does not receive any further IR signals.

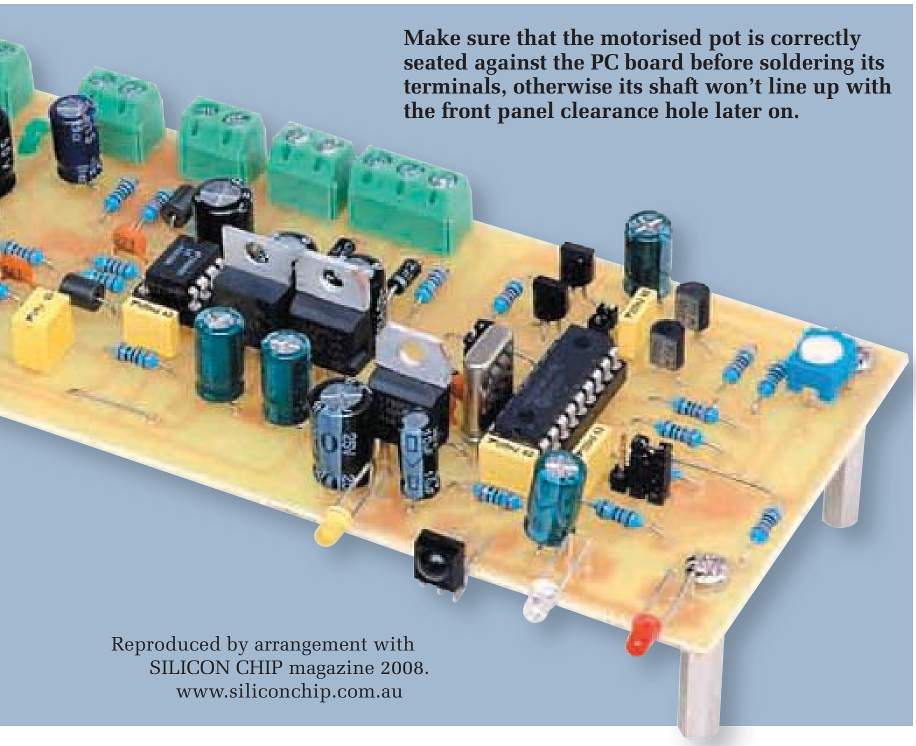
In addition, the potentiometer drive motor is enclosed by a Mumetal shield, which reduces any radiated electrical hash from the motor's commutator brushes. A 10nF capacitor connected directly across the motor terminals also prevents commutator hash from being transmitted along the connection leads, while further filtering is provided by a 100nF capacitor located at the motor output terminals on the PC board.

Coding options

Links LK1 and LK2 at RB7 and RB6 are used to program the different infrared coding options. The default selection is when both ports RB6 and RB7 are pulled high via their internal pull-up resistors – ie, when LK1 and LK2 are out. This selects the TV1 infrared remote control code and this will be suitable for most applications.

However, this code may also operate your TV and so we have provided options to select another code to prevent this from happening. The inset table in Fig.4 shows the linking options used to select either the SAT1 or SAT2 code. For example, installing LK2 (and leaving LK1 out) sets the code to SAT2.

Power for the circuit is derived from the amplifier's 22V DC supply and is fed in via a 22Ω resistor and a 100µF decoupling capacitor. The resulting rail is then applied to regulator REG3, which produces a +5V supply rail to power IC3, IRD1 and the H-bridge driver stage for



Make sure that the motorised pot is correctly seated against the PC board before soldering its terminals, otherwise its shaft won't line up with the front panel clearance hole later on.

the motor. A 10µF capacitor decouples the output of REG3, while the 100µF capacitor across IRD1 prevents this device from false triggering due to 'hash' on the +5V rail.

Software

The software files are available for download via the *EPE* Downloads site, access via **www.epemag.com**. Preprogrammed PICs are available from **Magenta Electronics** – see their advert in this issue for contact details.

Construction

All the parts for the Preamp & Remote Volume Control Unit are installed on a single PC board, coded 696, measuring 201 × 63mm. This board is available from the *EPE PCB Service*.

The external connections to the power supply and to the audio input and output cables are run via insulated screw terminal blocks. Fig.5 shows the assembly details.

As usual, begin by checking the board for defects and for the correct hole sizes. In particular, check that the motorised pot and the screw terminal blocks fit correctly and that the mounting holes are correct.

That done, start the assembly by installing the six wire links. You can straighten the link wire by securing one end in a vice and then pulling on the other end using a pair of pliers, to stretch it slightly. The resistors can then go in.

Table 1 shows the resistor colour codes, but you should also check them using a digital multimeter, as the colours can sometimes be difficult to decipher.

Next on the list are the four ferrite beads. These each have a wire link run through them, which is then soldered to the board. Follow these with the two diodes (D1 and D2), then install sockets for the three ICs. Make sure that each socket is oriented correctly (IC3 faces in the opposite direction to ICs 1 and 2) and that it's seated properly against the PC board.

In fact, it's best to solder two diagonally opposite pins of a socket first and then check it before soldering the remaining pins.

The MKT polyester and ceramic capacitors can now go in, followed by the non-polarised capacitors and the polarised electrolytics. Make sure that the latter are all correctly oriented and note that the 100µF capacitor to the left of LED3 must be rated at 25V (the other 100µF capacitors can all be rated at 16V).

Now install the transistors and 3-terminal regulators. Transistors Q1 to Q4 all go in the remote volume control section and must be oriented as shown. Be sure to use the correct type at each location. Q1 and Q3 are both BC327s, while Q2 and Q4 are BC337s. Don't get them mixed up.

The same goes for the three regulators. REG1 is a 7815, REG2 a 7915 and REG3 a 7805 – again, don't mix them up. These parts should all be inserted as far down as they will go, with their metal tabs facing towards the back of the board. No heatsinking is required for their metal tabs, since current requirements are only modest.

The 2-way DIL (dual-in-line) pin header for LK1 and LK2 can now be installed, followed by the 3-way header for LK3 and LK4. A 2-way pin header is

Table 1: Resistor Colour Codes

❑	No.	Value	4-Band Code (1%)	5-Band Code (1%)
❑	4	100kΩ	brown black yellow brown	brown black black orange brown
❑	2	22kΩ	red red orange brown	red red black red brown
❑	1	18kΩ	brown grey orange brown	brown grey black red brown
❑	1	10kΩ	brown black orange brown	brown black black red brown
❑	4	4.7kΩ	yellow violet red brown	yellow violet black brown brown
❑	7	1kΩ	brown black red brown	brown black black brown brown
❑	6	100Ω	brown black brown brown	brown black black black brown
❑	1	22Ω	red red black brown	red red black gold brown
❑	1	10Ω	brown black black brown	brown black black gold brown

Avoiding an earth loop with IRD1

If the supplied infrared receiver (IRD1) includes an external metal shield (see photo), then steps must be taken to insulate it from the chassis when the preamplifier is installed. That's because the shield is connected to the centre (GND) terminal of the device and a short between the shield and the metal chassis would create an earth loop. And that in turn would inject hum into the audio signal.

One method is to attach a short strip of insulation tape to the inside of the front panel, with a hole cut out to match the hole in the panel. Alternatively, it should be possible to insulate the front of the device and arrange it so that it just stands clear of the front panel.

If your infrared receiver module has a metal shield like this one, then be sure to insulate it from the front panel as described in the accompanying text.

Do not rely on the powder coating on the chassis to provide insulation! That's asking for trouble.

also used to terminate the motor leads (just to the right of Q1 and Q3). To install this header, first push its pins down so that their ends are flush with the top of the plastic, then install the header from the component side and solder the pins underneath.

This will give about 7mm pin lengths to terminate the leads from the motor, which are run underneath the PC board.

Crystal X1 (adjacent to IC3) can be installed either way around. Make sure it's seated correctly before soldering its leads, then install trimpot VR2 and the six screw terminal blocks. Be sure to use the screw terminal blocks specified in the parts list – they give more reliable connections when terminating thin audio cable leads than the type used on our prototype.

Mounting the motorised pot

It's absolutely critical to seat the motorised pot (VR1) correctly against the PC board before soldering its leads. If this is not done, then it won't line up correctly with its clearance hole in the amplifier's front panel later on.

In particular, note that the two lugs at the rear of the gearbox cover go through slotted holes in the PC board. Use a small jeweller's file to enlarge these if necessary.

Once the pot fits correctly, solder two diagonally opposite pot terminals and check that everything is correct before soldering the rest. The two gearbox cover lugs can then be soldered.

Once the pot is in place, the motor terminals can be connected to the two pin header at the other end of the board using light-duty hook-up cable. These leads are twisted together to keep them tidy and pass through a hole in the board immediately behind the motor. As shown, they are then secured to the underside of the PC board using cable ties and connected to the header pins (watch the polarity).

Don't forget to solder the 10nF capacitor directly across the motor terminals. As previously stated, it's there to suppress motor hash.

Mounting the LEDs

Fig.6 shows the mounting details for the infrared receiver (IRD1) and the three LEDs. As shown, the centre line of each lens must be 4mm above the board surface.

So how do you mount the LEDs accurately? Easy – just cut 11mm wide and 4mm wide templates from thick cardboard. The 11mm template serves as a lead bending guide, while the 4mm template is used as a spacer when mounting the LEDs – just push each LED down onto the spacer and solder its leads.

Hint: you can use sticky tape as a 'third hand' to hold each LED and the template in place during soldering.

IRD1's leads should also be bent as shown in Fig.6 and the photos. This will allow a small amount of 'give' in the leads when the lens later contacts the back of the front panel (ie, it will allow IRD1 to 'spring' back slightly and keep the lens against the panel).

Finally, complete the board assembly by installing the quick connector. As with previous boards, it's held in place using an M4 screw, a flat washer, a shakeproof washer and a nut (see Fig.3 last month).

Initial checks

Before plugging in any of the ICs, it's a good idea to check the supply voltages. However, if you don't have the power supply running yet (or a suitable bench power supply), this can wait until the final assembly in the chassis.

Assuming you do have a power supply, connect the +22V, –22V and 0V leads to CON6 and switch on. Now check the voltages on pins 8 and 4 of the two 8-pin IC sockets (ie, between each of these pins and 0V). You should get readings of +15V (pin 8) and –15V (pin 4) respectively.

Similarly, check the voltage on pin 14 of IC3's socket – you should get a reading between 4.8V and 5.2V.

If these voltages are correct, switch off and plug the ICs into their sockets, taking care not to zap them with static electricity. Note that IC1 and IC2 face one way, while IC3 faces the other way.

Remote volume control testing

If you don't have a dual power supply, you can check just the remote volume control section using a single rail 9V to 15V supply (connect this between the +22V and 0V terminals on CON6). As before, check the voltage on pin 14 of IC3's socket (it must be between 4.8V and 5.2V), then switch off and plug IC3 into its socket.

In addition, insert the jumper link for LK3, to enable the Mute return feature, but leave LK1 and LK2 out for the time being (to accept the TV code from the remote control).

Further testing requires a universal remote control. These range from single TV remote controls with limited functions to elaborate models capable of operating many different types of equipment.

Note, however, that simple TV remote controls will only operate this project using the TV code (026). That can cause problems if you have a Philips TV set located in the same vicinity as the amplifier, because the remote control will probably operate the TV as well. This is easy to solve – just use a multi-item remote control so that a different code can be used (either 424 for SAT1 or 425 for SAT2)

An example of a TV-only remote control is the Jaycar AR-1703. Multi-item remote controls include the Altronics A-1009 and the Jaycar AR-1714.

Programming the remote

The best approach here is to initially program the remote control for a Philips brand TV (just follow the instructions supplied with the unit). In most cases, programming involves simultaneously pressing the 'Set' button and the button for the item that is to be operated. In other words, press the Set and TV buttons together and enter a number for a Philips TV set.

In this case, the Altronics A-1009 uses the number 026 or 191 and the Jaycar AR-1703 uses 11414. If you are using a different remote control, just select a number for a Philips TV set. If you later find that this doesn't work, try another number for a Philips TV.

Having programmed the remote, rotate trimpot VR2 fully anticlockwise. That done, check that the motor turns the potentiometer clockwise when the remote's Volume Up and Channel Up buttons are pressed.

It should travel fairly quickly when Volume Up is pressed and at a slower rate when Channel Up is used.

Now, check that the volume pot runs anticlockwise using the Volume Down and Channel down buttons. If it turns in the wrong direction, simply reverse the leads to the motor. Check that the blue Acknowledge LED flashes each time you press a button on the remote.

Next, set the pot to mid-position and hit the Mute button. The pot will rotate anti-clockwise and as soon as it hits the stops, the clutch will start to slip. While this is happening, slowly adjust VR2 clockwise until the motor stops.

Now press Volume Up to turn the potentiometer clockwise for a few seconds and press Mute again. This time, the motor should stop as soon as the pot reaches its minimum position.

Note that a programmed timeout of 13 seconds will also stop the motor (if it hasn't already stopped) after Mute is activated. This means that you have to adjust VR2 within this 13s period, otherwise the timeout will stop the motor.

If it stops prematurely or fails to stop at all (ie, the motor runs for the full 13 seconds), try redoing the adjustment. Once the adjustment is correct, pressing the Mute button a second time should accurately return the potentiometer to its original position.

Universal infrared remote controls

The Remote Volume Control circuit is designed to work with most universal ('one-for-all') infrared remotes. It recognises the RC5 protocol that was originally developed by Philips, so the remote must be programmed for a Philips (or compatible) appliance before use.

Most universal remotes are provided with a long list of supported appliances and matching codes. To set the remote to work with a particular piece of gear, it's usually just a matter of entering the code listed for the manufacturer (in this case, Philips), as detailed in the instructions.

You'll also note that different codes are provided for TV, CD, SAT, and so on. This allows two or more appliances from the same manufacturer to be operated in the same room and even from the same handpiece.

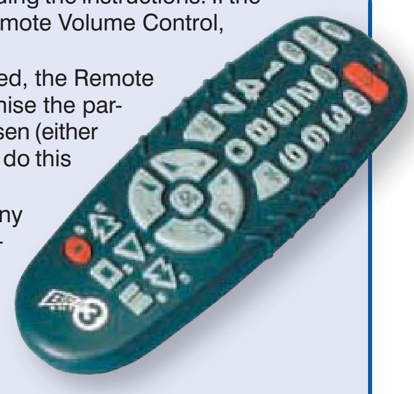
This multiple addressing capability can also be useful in our application too. Normally, we'd program the remote to control a TV, as this works with the control module. But what if you already have a Philips TV (or some other model that uses the RC5 protocol)? Well, in that case, you simply use the SAT1 or SAT2 code instead, as the Remote Volume Control can also handle these.

Typically, to set a remote to control a Philips TV, you first press and hold 'SET' and then press 'TV'. This puts the remote in programming mode, as indicated by an LED, which should remain illuminated.

You then release both keys and punch in one of the listed Philips TV codes. For this project, code 026 works well. The red LED should then go out, after which the remote is ready for use. All universal remotes can be programmed in a similar manner, but if in doubt, try reading the instructions. If the first code listed doesn't work with the Remote Volume Control, then try another.

Once the remote has been programmed, the Remote Volume Control must be set up to recognise the particular equipment address that you've chosen (either TV, SAT1 or SAT2). The details on how to do this are in the main text.

Although this project should work with any universal remote, we've tested the following popular models: AIFA Y2E (Altronics A-1013), AIFA RA7 (Altronics A-1009) and Jaycar AR-1703. For all these models, the set-up codes are as follows: TV = 026, SAT1 = 424 and SAT2 = 425. Note, however, that the AIFA Y2E doesn't have a mute button.



As mentioned earlier, links LK1 and LK2 change the codes for the infrared transmission – see the table in Fig.4. You will only need to install one of these links (to select SAT1 or SAT2) if you have a Philips TV. Remove link LK3 and install link LK4 if the Mute return feature is not required.

Note that with a new motorised potentiometer, the clutch will require a little 'wearing in' to evenly spread the lubricant in the slipping sections. This can be done simply by turning the pot shaft by hand a few times before use. Readjust VR2 for best results after you do this.

Avoiding a hum loop

Finally, note that the power supply earth (0V) is *not* connected to the left and right channel earth tracks on the preamplifier PC board. This avoids a hum loop, since the two channels are normally earthed back through the power amplifiers via their signal leads.

However, if you want to use the preamp on its own, *both* the left and right channel signal earths on the board must be connected to the 0V rail for the power supply. This can be done by connecting insulated wire links between the relevant screw terminal blocks.

This view shows the Preamplifier & Remote Volume Control module mounted inside the completed Class-A Stereo Amplifier. The final assembly, wiring and adjustment details will be published next month.

That's all for this month. In Part 5, we'll show you how to assemble all the modules into a custom metal chassis to produce a complete high-quality class-A stereo audio amplifier. *EPE*

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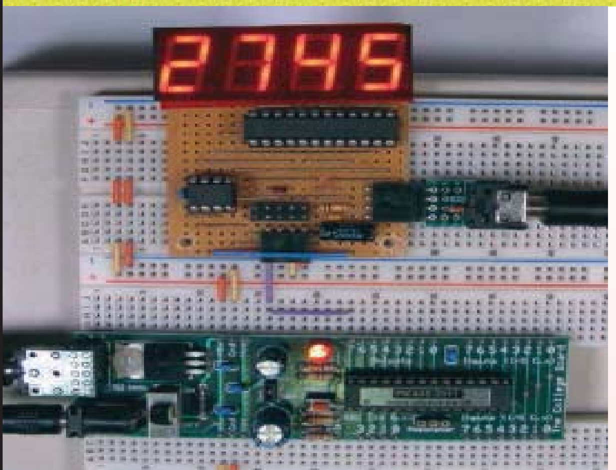

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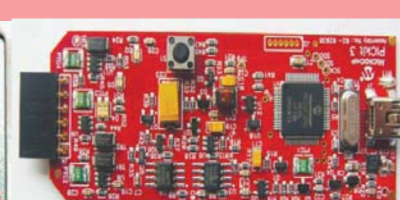

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Stereo Class-A Amplifier Pt.5

By GREG SWAIN

Chassis assembly, wiring and adjustment details

In this final article, we show you how to build a high-performance 20W Class-A Stereo Amplifier using the modules described over the last few months.

IN the Oct '08 and Nov '08 issues, we published the circuit and assembly details for our new high-performance *20W Class-A Stereo Power Amplifier* modules, along with a suitable *Power Supply* module. Then, in the Dec '08 issue, we described a *Speaker Protection & Muting* module and followed that up in Jan '09 with a *Low-Noise Preamplifier & Remote Volume Control*.

This month, we show you how to assemble everything into a custom-made steel chassis that's been designed by Altronics (**www.altronics.com.au**). This precision laser-cut chassis is supplied with all the holes drilled and with pre-punched front and rear panels with screened lettering.

This case is similar to their '2U' deluxe rack cases (but is much deeper) and features a bevelled front panel. The completed amplifier looks very professional, although at 420 × 425 × 88mm (W × D × H) it's really quite a large unit. This size is necessary to accommodate the large finned heatsinks used for the power amplifiers and to allow the various modules to be logically placed (and separated) inside the chassis.

The large chassis size is also important to aid ventilation, as the main heatsinks run quite hot in operation (about 30° above ambient). In addition, the bottom of the chassis and the lid have large ventilation slots, which line up with the heatsink fins, to allow the air to circulate through them.

That's one of the drawbacks of a class-A amplifier – they generate lots of heat that has to be dissipated.

Now, let's assume that you've completed all the modules and that you're ready to mount them in the chassis and install the wiring. Here's how to go about it.

Preparing the case

The supplied case has a tough powder-coating that's also a good insulator. **However, you *must* ensure that all sections of the case, including the side panels and the front and rear panels, are correctly earthed and that means ensuring they make good electrical contact with each other. There are two reasons for this:**

1) All sections of the case must be connected to the mains earth to ensure safety

2) Correct earthing is essential to keep RF interference out of the audio circuitry.

The first job is to ensure that the two side panels, the front and rear panels and the lid are all earthed to the bottom section of the chassis. This is done by using an oversize drill to remove the powder coating from the countersunk screw holes. Use a drill that's slightly smaller in diameter than the screw heads and be sure to remove the powder coating right back to the bare metal.

Don't just do this for one or two holes – do it for *all* the holes in each panel. Provided you use a drill that's not too big, the bare metal will later be covered by the screw heads.

Next, scrape away the powder coating around the screw holes inside the panels, the underside of the lid and from the matching contact areas around the screw holes in the chassis. This includes the contact areas around the screw holes on the inside folded sections of the front panel. That way, when the case is assembled, earthing takes place via the

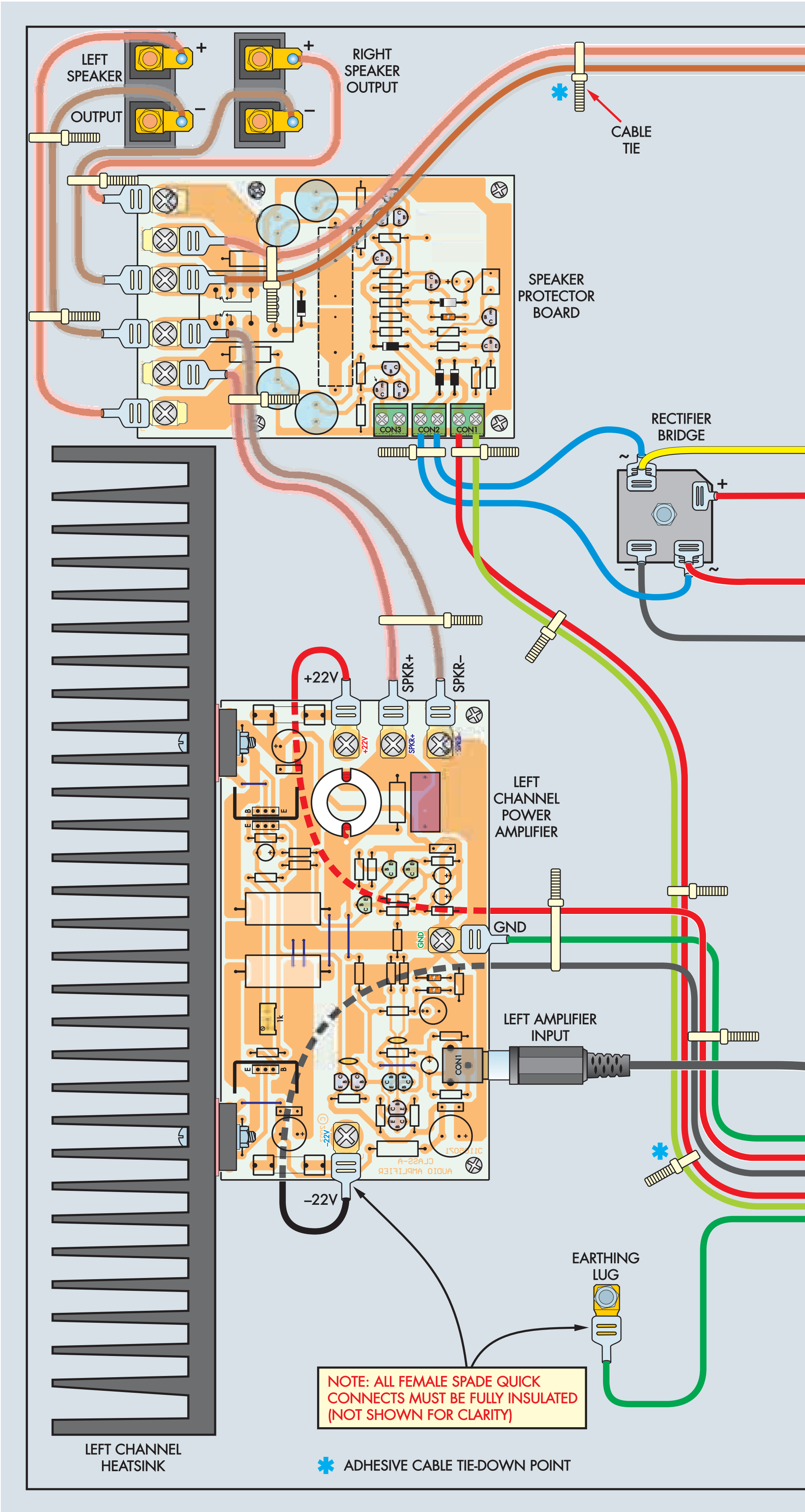


Fig.1: follow this diagram and the photos to install the parts in the chassis and complete the wiring. Note that the supply leads to the modules, transformer and mains switch are twisted together – see photos and text.

screws themselves and also via direct metal-to-metal contact between the various sections.

The transformer mounting bolt must also be earthed. This means that you have to remove some of the powder coating from around the mounting hole on the outside of the chassis (ie, from under the bolt head). The same goes for all other mounting screws that go through the bottom of the chassis. In particular, make sure that you clear away the powder coating from around the six heatsink mounting holes.

Once you've done all this, remove the front panel, wrap it up and put it to one side, so that it doesn't get scratched or damaged. It doesn't take much of an accident to spoil the panel's appearance while you are installing the parts in the chassis and completing the interwiring.

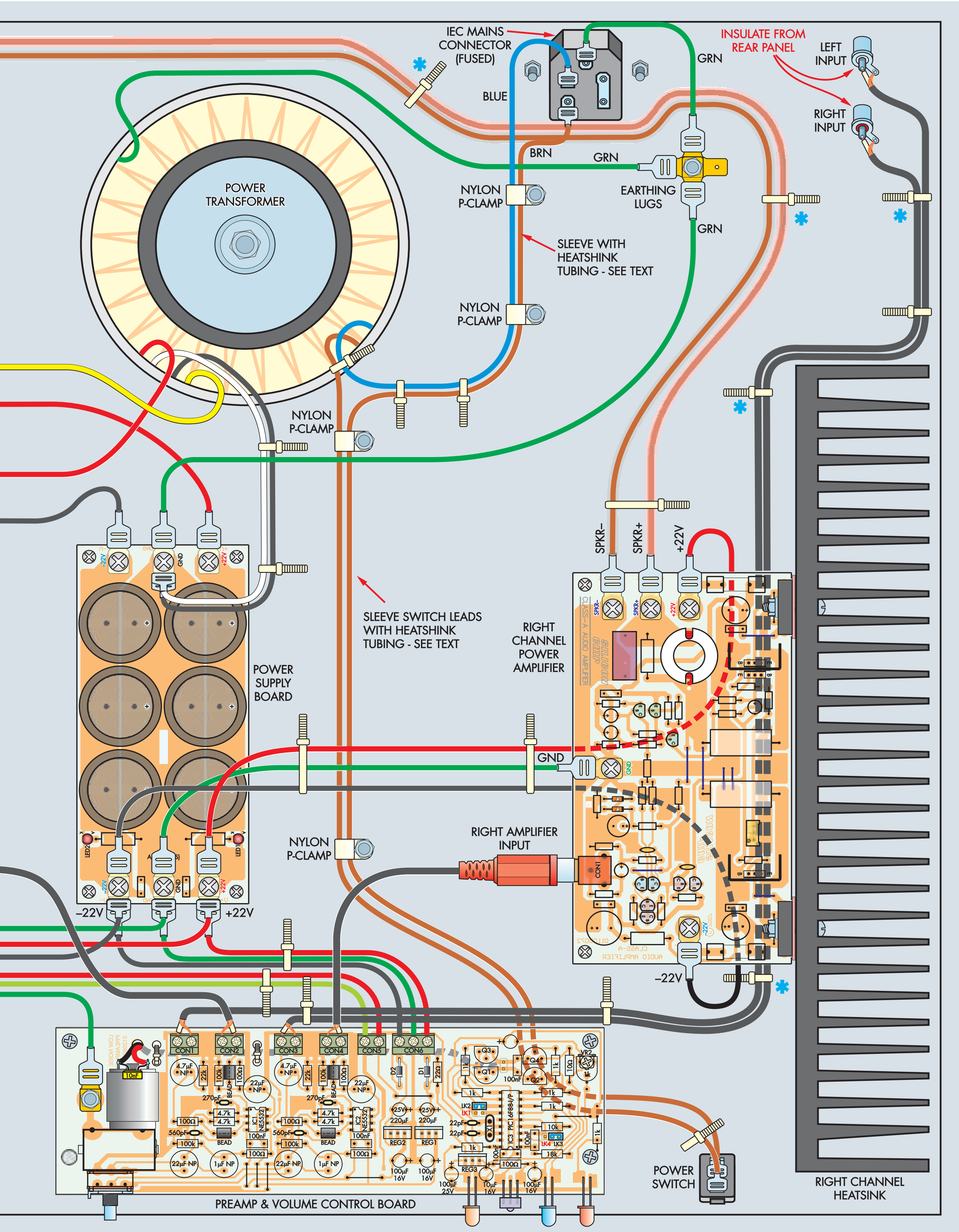
Installing the hardware

You can now start installing the hardware in the case – see Fig.1. Begin by securing the IEC (fused) power socket to the rear panel using two 6g × 12mm countersink self-tappers. That done, mount the two insulated RCA phono input sockets and the two loudspeaker terminal panels.

Note that the white (left) colour-coded RCA phono socket goes to the top, while the red (right) socket goes to the bottom. The loudspeaker terminal pairs go in with their red (positive) terminals towards the top and are again secured using 6g × 12mm countersink self-tappers.

The 35A bridge rectifier can go in next. Because it uses the chassis for heatsinking, it's important to ensure good metal-to-metal contact. It's mounting area should be completely free of powder coating – if it isn't, mark out the area and remove the powder coating using a small grinding tool.

Now smear the underside of the 35A bridge rectifier (BR1) with heatsink compound and bolt it to the chassis using an M4 screw, star washer and nut. Fig.1 and the photos show BR1's


IEC MAINS CONNECTOR (FUSED)
BLUE
BRN
GRN
INSULATE FROM REAR PANEL
LEFT INPUT
RIGHT INPUT
POWER TRANSFORMER
NYLON P-CLAMP
EARTHING LUGS
SLEEVE WITH HEATSHINK TUBING - SEE TEXT
SPKR–
SPKR+
+22V
SLEEVE SWITCH LEADS WITH HEATSHINK TUBING - SEE TEXT
RIGHT CHANNEL POWER AMPLIFIER
POWER SUPPLY BOARD
GND
RIGHT AMPLIFIER INPUT
–22V
+22V
POWER SWITCH
RIGHT CHANNEL HEATSINK
PREAMP & VOLUME CONTROL BOARD

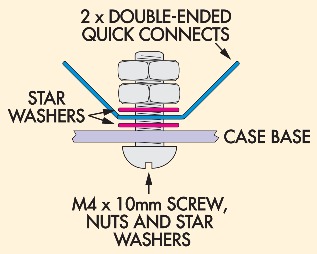


Fig.2: the Altronics case will come with the main earth lugs mounted in place. However, if you're using a different enclosure, here's how to install the chassis earth point. Two nuts are used to permanently lock the assembly in place. Make sure that it forms a sound electrical contact with the chassis.

mounting location and orientation. It's mounted with its positive DC output at top right.

Chassis earth lugs

Fig.2 shows the mounting details for the main chassis earth lugs. This assembly consists of two double-ended quick-connect spade terminals, which are bolted to the chassis using an M4 × 10mm machine screw, two star washers and two nuts. The second nut on top locks the first nut in place, so that there's no possibility of the earth terminals coming loose.

The chassis supplied with the kit will come with the earth lugs mounted in position. However, if you are using a different case, then you will have to remove the powder coating yourself. To do this, temporarily bolt one of the double-ended quick connects to the chassis and use a pencil to outline the contact area. The connector can then be unbolted and the powder coating removed using a sharp implement or a small grinding tool.

The two double-ended earth lugs can then be bolted in position. Be sure to do the nuts up nice and tight, to ensure a reliable earth.

A second earth lug is mounted at the front of the chassis, to the left of the preamp board. This is a single-ended lug and is used to ensure a reliable earth connection for the body of the volume potentiometer.

Installing the modules

The five PC-board modules can now be installed in the chassis. Note that these modules are all mounted on 10mm tapped stand-offs, except for the preamplifier module, which mounts on three 25mm tapped stand-offs.

Begin by mounting the left and right channel power amplifier modules. These should already be attached to their heatsinks and it's just a matter of lining these up with their mounting holes in the chassis and bolting them into position using M4 × 10mm machine screws and star washers. The star washers go under the heads of the screws and bite into the chassis to ensure that the heatsinks are securely earthed.

Note: do not over-tighten these screws. The heatsinks are made of aluminium and it's all too easy to strip the threads if you are ham-fisted.

Once the heatsink screws are in, the spacers fitted to the power amplifier boards can be secured to the chassis using M3 × 6mm screws and flat washers. If necessary, loosen off the heatsink screws under the chassis to get everything to line up, then do the screws up nice and tight.

Preamplifier module

The preamplifier module can now be mounted. As previously mentioned, the preamplifier is secured using only three of its four mounting holes – the hole adjacent to the volume control pot is not used. This avoids placing strain on the pot's soldered joints and in any case is unnecessary, since the pot's ferrule is also secured to the front-sub-panel.

Before mounting the preamp, fit a flat washer over the pot's threaded ferrule. That done, fit the three 25mm tapped spacers, then slip the preamp board into position and secure it to the front sub-panel by fitting the nut and a shakeproof washer to the pot. Do this nut up firmly but don't over-tighten it, to avoid stripping the thread.

Finally, the three spacers can be secured to the chassis using M3 × 6mm machine screws and washers.

The three indicator LEDs and the IR LED on the preamp board all go through a cutout in the front sub-panel. Provided you've installed them correctly, as shown in Part 4 last month, they should all line up neatly with their respective holes when the front panel is later installed.

Note that the photos show these parts going through separate holes in the front sub-panel. The chassis supplied for kits will feature a large cut-out in the sub-panel instead.

Note also that if the infrared receiver module (IRD1) has a metal shield, then it must be insulated from the front panel (see p36, Jan '09).

Power supply module

The power supply board is next on the list, but first you have to add some extra spade connectors. First, you need to install three extra single-ended connectors at the DC output end of the board, to go with the existing double-ended connectors. That done, install an extra double-ended connector at the GND terminal (to go with the existing single-ended connector) at the input end of the board – see Fig.1.

Make sure that the screws that hold these connectors in place are done up nice and tight. You will need a screwdriver to hold the head of each screw in place and a ratchet-driven socket to tighten up the nuts.

Having added the extra connectors, the power-supply board can now be mounted in position. Secure it using M3 × 10mm screws and flat washers.

Leave the power toroid transformer out for the time being – that step comes a little later, after you've installed the low-voltage DC wiring.

Wiring up

Fig.1 shows the wiring routes. It's not nearly as intimidating as it appears at first sight, as most of it simply consists of DC supply wiring to the various modules. In addition, there's a small amount of audio signal cabling, plus the loudspeaker cabling and the mains wiring.

As can be seen, most of the supply wiring is terminated using insulated female spade connectors. These simply plug into the quick connect spade terminals on the various modules. Screw terminal blocks handle most of the other terminations, the exceptions being the RCA phono input sockets on the two audio power amplifier boards.

By the way, a ratchet-driven crimping tool (see photo) is an absolute necessity when it comes to installing the crimp connectors. Low-cost automotive type crimpers are definitely not suitable here, as their use would result in unreliable and unsafe connections – particularly where the mains wiring is concerned.

This chassis view clearly shows the routing of the loudspeaker cable from the right channel power amplifier. It runs along the bottom of the rear panel and is secured using adhesive cable tie mounts and cable ties.

As shown in the photos, all the supply leads are tightly twisted together. This not only keeps the wiring neat but also minimises hum pick-up, since the hum fields are effectively cancelled out.

There's an easy way to twist the leads together, and that's by using a hand drill. All you have to do is secure one end of the leads in a vice and the other end in the drill chuck. You then rotate the drill handle until you get a nice even lead twist along the full length of the cable.

Tight squeeze

Make the twists reasonably tight but don't overdo it – the wire will break through the insulation if you do. Once it's done, trim the ends to remove any damaged insulation and fit spade connectors to the leads at one end of the cable only. The spade connectors are fitted as follows:

1) Trim 6mm of insulation from the end of a lead and twist the wire strands together
2) push the lead into the connector until the insulation hits the internal collar
3) Crimp the connection using the crimping tool
4) Check that the connection is secure and properly insulated, with no wire strands outside the connector (this is particularly important for the 230V AC wiring).

The leads at the other end of each cable are also later fitted with spade connectors, after they have been run to their destinations and cut to the correct length.

It's best to install the low-voltage DC wiring first. This can go in as follows:

1) Install the supply wiring to the two power amplifiers. These cables should be run using extra heavy-duty red, green and black leads. Twist the leads together and initially fit spade connectors to the power supply ends only. That done, plug each cable into the power supply board and route it to its respective power amplifier board. When it reaches the amplifier board, cut the green lead to length, fit it with a spade connector and plug it in. The red and black leads then continue under the amplifier to the centre of the board. They then diverge at right

You need a ratchet-type crimping tool

One essential item that's required to build this amplifier is a ratchet-driven crimping tool, necessary for crimping the insulated quick-connect terminals to the leads.

Don't even think of using one of the cheap (non-ratchet) crimpers that are typically supplied in automotive crimp kits. They are not up to the job for a project like this, as the amount of pressure that's applied to the crimp connectors will vary all over the place. This will result in unreliable and unsafe connections, especially at the mains switch and IEC socket terminals.

By contrast, a ratchet-driven crimping tool applies a preset amount of pressure to ensure consistent, reliable connections.

angles and are routed to the +22V and –22V terminals.

2) Install the +22V, 0V and –22V supply wiring between the power supply board and the preamplifier.
3) Install the +22V and 0V wiring between the preamplifier and the loudspeaker protector module. Note that this wiring actually runs behind the bridge rectifier (Fig.1 shows it in front for clarity) and is tied down to one of the transformer ventilation slots. An adhesive cable tie mount at the front left corner of the power supply board provides a second anchorage point.
4) Install the ±22V wiring between the bridge rectifier (BR1) and the power supply board.
5) Install earth leads from the power supply board to the main chassis earth point and from the preamplifier board (near the volume pot) to its adjacent chassis earth.

AC-Sense leads

The two 'AC-Sense' leads that run from the bridge rectifier to the loudspeaker protector are next on the list. These are the blue leads that run to BR1's AC terminals in Fig.1.

First, twist the two leads together and fit one end of each lead with a piggyback crimp connector (see photo opposite page). That done, plug these into the AC (~) terminals of the bridge rectifier, then route the leads to the loudspeaker protector and trim them to length. Finally, strip about 5mm of insulation from the ends of the leads and tin them before connecting them to the screw terminal block (CON2).

If you route these leads as shown in the photos, they can be secured to the chassis using a cable tie that passes through one of the transformer ventilation slots. A second cable tie adjacent to CON2 is also a good idea.

Audio input wiring

The audio input signal leads can now be run from the rear panel to the preamplifier. These leads should be run using figure-8 (stereo) screened audio cable (ie, with the inner conductor individually shielded).

Route these leads exactly as shown and secure them using cable ties and adhesive cable tie mounts. The locations of the latter are indicated on Fig.1.

Note that the shield leads are separately connected to their respective solder lugs on the insulated RCA input sockets. Do *not* connect these shield leads together or to chassis, otherwise you'll get an earth loop.

At the preamplifier end, trim each cable to length, then strip about 14mm of the outer insulation away from each conductor in turn and carefully separate and twist the screening braid wire strands together. That done, strip about 10mm of insulation from each inner conductor, then double each bared end back on itself, twist it together and lightly tin with solder. The shield wires can also be 'doubled up', twisted and tinned.

Now secure the audio input leads to the screw terminal blocks. **Note that it's important to do these screw connections up nice and tight, otherwise the signal-to-noise ratio will be compromised.**

Some of the left over figure-8 audio cable can now be used to make the two audio leads that run from the preamplifier to the power amplifier modules. Separate the cable into two separate leads and fit an RCA phono plug to one end of each lead (red for the right channel, black for the left).

Make sure that each shield wire connects to the 'earthy' side of its phono plug (ie, to the terminal that connects to the outer collar).

The other ends of these cables can then be trimmed to length and connected to screw terminal blocks CON2 and CON4 on the preamplifier. Be sure to tin the leads as before, and again make sure the connector screws are done up tightly.

Loudspeaker cabling

The loudspeaker leads, both to and from the loudspeaker protector module, are run using heavy-duty 90/0.18 speaker cable. The cables are terminated at both ends using female spade connectors and must be routed exactly as shown in Fig.1 and the photos.

In particular, note the path for the loudspeaker cable from the right channel power amplifier. This must be kept as far away as practical from the mains wiring between the IEC socket and the power transformer.

As shown, it runs around the chassis earth terminal and then runs along the bottom section of the rear panel (behind the transformer) to the

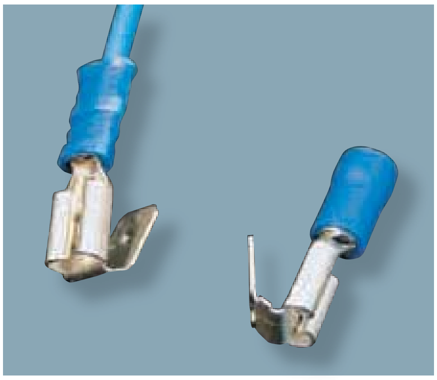
Where to buy complete and shortform kits

A kit of parts for the 20W Stereo Class-A Amplifier (Cat. K5125) is available from Altronics, 174 Roe St, Perth, WA 6000, Australia. The kit is complete and includes the five modules (unassembled) and a pre-punched steel chassis similar to that shown in the photographs.

Alternatively, you can purchase individual kit modules (but not the chassis) separately. Check the Altronics website at www.altronics.com.au for further details.

Note: the kit does not include an infrared remote control handpiece. This must be purchased separately. Almost any universal remote should be suitable – eg, Altronics Cat. A 1009 or Jaycar AR-1703.

If your infrared receiver module has a metal shield like this one, then be sure to insulate it from the front panel, as described last month.



The AC-Sense leads from the loudspeaker protector module are terminated in piggyback crimp connectors at the bridge rectifier end, as shown here.

Parts list for Class-A Stereo Amplifier

1 custom pre-punched steel case with screened front and rear panels (Altronics)
1 32mm black aluminium knob with grub screw
1 16V + 16V 160VA magnetically-shielded toroidal transformer (Altronics MA 5417)
1 SPST 10A 250V AC rocker switch
1 chassis-mount fused male IEC socket
1 4A 250V AC slow-blow fuse (M205)
1 230V AC 3-pin IEC mains power lead
3 6.3mm double-ended chassis-mount spade lugs
5 6.3mm single-ended chassis-mount spade lugs
40 6.3mm female spade fully-insulated connectors
2 piggyback crimp connectors
1 red RCA phono plug
1 black RCA phono plug
2 chassis-mount *insulated* RCA phono sockets (red and black)
2 2-way loudspeaker terminal panels
1 pot nut and washer
5 P-clamps
20 M3 × 6mm screws
20 M3 shakeproof washers
20 M3 flat washers
13 M4 × 10mm screws
1 M4 × 16mm screw (to secure bridge rectifier BR1)
22 M4 flat washers
1 M4 shakeproof washer (for bridge rectifier BR1)
Heatsink compound for BR1

Modules

1 right-channel class-A power amplifier module (Altronics K 5126)
1 left-channel class-A power amplifier module (Altronics K 5127)
1 power supply module (Altronics K 5128)
1 preamp and remote volume control module (Altronics K 5129)
1 loudspeaker protector module (Altronics K 5124)

Wire/cable, miscellaneous

1m brown 32/0.20 extra heavy-duty hook-up wire (mains rated)
2m red 32/0.20 extra heavy-duty hook-up wire
1m black 32/0.20 extra heavy-duty hook-up wire
2m green 32/0.20 extra heavy-duty hook-up wire (mains rated)
250mm 24/0.20 heavy-duty blue hook-up wire
1m figure-8 shielded audio cable
1m heavy-duty 90/0.18 speaker cable
40 small nylon cable ties
7 adhesive cable tie mounts
500mm of 10mm diameter heatshrink tubing

loudspeaker protector module. The cable is anchored in position using several adhesive cable tie mounts. Two of these are attached to the bottom of the rear panel, while the third sits in front of the chassis earth lugs.

Mounting the transformer

The toroidal mains transformer can now be bolted into position. This transformer is supplied with two neoprene rubber washers – one sits under the transformer (ie, between the transformer and chassis), while the other sits on top. A metal cup washer is then placed over the top rubber washer and the whole assembly secured using a large bolt that passes up through the centre of the transformer.

Before installing the mounting bolt, check that the powder coating has been cleared from around its hole at the bottom of the chassis (this is necessary to ensure the bolt is correctly earthed). Now, install the bolt and do the nut up finger tight, then rotate the transformer so that its yellow secondary lead is exactly in line with the GND (centre) connection on the adjacent power supply board.

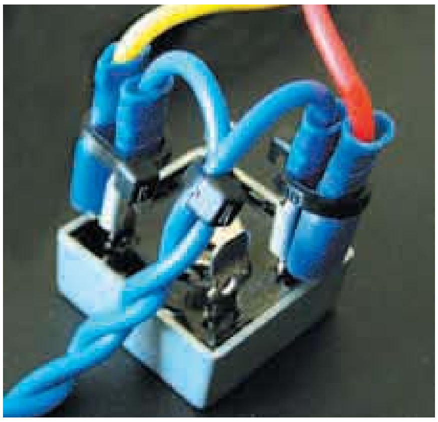
Finally, do the nut up firmly but don't over tighten it, otherwise you'll distort the metal chassis.

Note: Fig.1 shows both the transformer and the preamplifier module offset to the right, compared to their true locations in the chassis. This has been necessary to keep these parts clear of the magazine centre.

As previously mentioned, the transformer leads are all the correct length to reach their destinations and are pre-fitted with female spade quick connects. We'll deal with the secondary wiring first – all you have to do is twist the various lead pairs together and plug them into the relevant quick connect terminals on bridge rectifier BR1 and the power supply module.

First, twist the white and black leads together (to form the 0V centre-tap) and connect them to the adjacent GND point on the power supply module. That done, twist the red and

The RCA phono input sockets must be fully insulated from the chassis. The audio cable shield wires go to the individual solder lugs – do not join them or connect them to chassis at this point, as this would create an earth loop.



The transformer's red and yellow secondary leads plug into the piggyback connector at the bridge rectifier (BR1) as shown here. They should then be strapped using cable ties, so that the connectors cannot short against BR1's metal case.

yellow secondary leads together and plug them into the piggyback spade connectors on the AC terminals of BR1.

There's one important wrinkle you have to watch out for when plugging in the transformer secondary leads – it's all to easy to push the male lug of each piggyback connector down so that it shorts against the metal case of BR1. To avoid this, bend each male connector upright after plugging in the transformer lead and secure it in this position using a cable tie (see photo).

It's also a good idea to fit cable ties at both ends of the twisted pairs to keep the wiring tidy.

Mains wiring

It's now time to connect the transformer primary leads (brown and blue) and install the rest of the mains wiring. Take particular care with the mains wiring – your safety depends on it. In particular, be sure to use fully insulated spade connectors for all connections to the IEC socket and mains switch.

As shown in Fig.1, the transformer's blue primary lead connects to the Neutral terminal on the IEC socket, while its brown primary lead runs directly to the top terminal of the mains switch. In addition, you need to run a heavy-duty (32/0.20) mains-rated cable (brown) between the bottom terminal of the mains switch and the Live terminal of the IEC socket.

The best place to start this wiring is at the power transformer. Here's the procedure, step-by-step:

STEP 1: run the primary leads straight down the side of the transformer to the chassis and secure them together at top, bottom and centre using three cable ties.

STEP 2: cut a 600mm length of brown 32/0.20 heavy duty cable (this will be used to connect the IEC socket Live terminal to the mains switch).

STEP 3: twist this lead together with the brown primary lead. Start of the primary lead's quick connector and twist the leads together all the way back to the base of the transformer.

STEP 4: Slip a 320mm length of 10mm-diameter heatshrink tubing over this twisted pair and lightly shrink it into place using a hot-air gun. Be careful not to apply too much heat – you don't want the cable insulation to melt (gently does it)!

STEP 5: Secure this cable in position using the nylon P-clamps, as shown in Fig.1. Note the orientation of the P-clamps – the cable should run adjacent to the power supply board, so that it is well away from the righthand power amplifier. The switch end of the cable runs under the preamp and must be routed exactly as shown.

STEP 6: Trim the switch end of the added brown lead to the same length as the brown primary lead and crimp on a fully-insulated spade connector. Make sure that all the wire strands go inside the connector – a strand outside the connector will be dangerous.

STEP 7: Attach the front panel to the amplifier chassis and clip the mains switch into position. The two switch terminals go towards the top of the panel.

STEP 8: Connect the two spade connectors to the switch terminals. The transformer's primary lead goes to the top terminal. Use a cable tie to secure the leads at the switch terminal.

STEP 9: Twist the added brown lead with the blue primary lead all the way to the latter's spade connector.

STEP 10: Slip a 120mm length of 10mm-diameter heatshrink tubing over this twisted pair and lightly shrink it into place using a hot-air gun (gently does it).

STEP 11: Secure this section of the cable in position using another two nylon P-clamps. As before, these should be orientated exactly as shown in Fig.1.

STEP 12: Trim the brown cable to length and crimp on a female spade connector.

STEP 13: Plug the connectors into the IEC socket. The blue lead goes to the neutral terminal while the brown lead goes to Live.

STEP 14: Further secure the leads using cable ties – two between the transformer and the first P-clamp and one right at the IEC socket.

STEP 15: Prepare a 100mm-long earth lead with female spade connectors at either end and connect it between the earth terminal on the IEC socket and a spare chassis earth lug.

STEP 16: Fit a 4A slow-blow fuse to the IEC socket.

STEP 17: Secure all the wiring in the amplifier by fitting cable ties as shown in Fig.1. This not only improves the appearance by keeping everything tidy but ensures reliability as well.

In particular, make sure that the 230V mains wiring is properly secured by the P-clamps and by fitting cable ties immediately behind the spade connectors at the IEC socket and the mains switch.

Initial checks

That completes the wiring, but there are a few things to check before plugging in a mains cable and switching on. Just follow this step-by-step checklist:

1) Check the 230V wiring to the IEC socket, mains transformer and mains switch to ensure all is correct. In particular, the

Ditching the preamp and using a conventional volume pot instead

One of the options that you have in building this unit is to ditch the Preamplifier & Remote Volume Control module and use a dual 10kΩ log pot as the volume control instead.

This option would typically be used if you wanted to use a CD player to drive the power amplifier modules – the signal output from a CD player is usually (but not always) sufficient to drive the amplifier modules to full power output.

The advantage of this scheme is that you save money (ie, the cost of the preamplifier) and construction time. But there are a couple of disadvantages. First, as mentioned last month, using a simple volume control varies the input impedance to the power amplifiers, thereby slightly degrading the signal-to-noise ratio. And second, your CD player may not be able to drive the amplifiers to full output power on CDs that give below-average output signal levels.

Another disadvantage is that you no longer have the convenience of remote volume control.

If you do want to omit the preamplifier, Figs.3 and 4 show how it's done. As shown, the incoming left and right channel signals are fed to the top of the pot and the attenuated signals on the pot wipers are then fed directly to the power amplifier inputs. Fig.3 shows the circuit, while Fig.4 shows the wiring diagram.

External preamp

If you intend using an external preamplifier, you can omit the volume control altogether and simply run the audio input leads direct to the class-A power amplifiers.

What about all those blank holes on the front panel? Easy – just mount the necessary parts to fill in the holes but don't wire them up. The LEDs can be secured at the rear using epoxy resin.

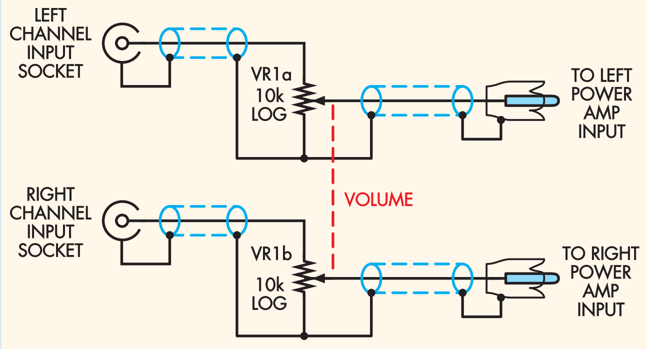


Fig.3: this circuit shows how to use a dual 10kΩ log pot as the volume control.

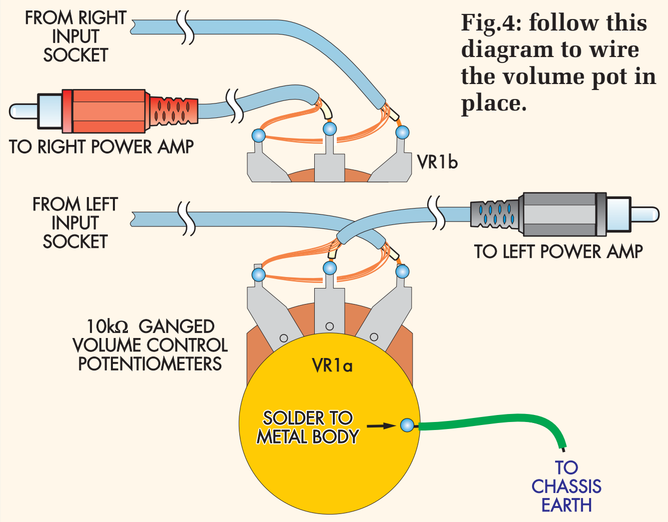


Fig.4: follow this diagram to wire the volume pot in place.

female spade connectors should all be tightly crimped, the connectors must be fully insulated and there must be no wire strands outside these connectors.

In addition, all spade connectors should be a tight fit onto their lugs, especially at the IEC socket, the mains switch and the bridge rectifier. Re-tension any connectors that slide on too easily.

2) Check that BR1's positive and negative terminals connect to the correct terminals on the power supply board.

3) Check that all the electrolytic capacitors on the power supply board are installed with the correct polarity. These things have a nasty habit of exploding if they're in the wrong way round. The same goes for other electrolytics across the supply rails on the other modules.

In fact, it's not a bad idea to wear safety glasses when switching on for the first time, just in case you do have a capacitor in the wrong way around or you accidentally reverse the supply polarity. Exploding capacitors and eyeballs generally don't mix too well!

4) Use a multimeter to confirm that all the chassis panels are correctly earthed. **Do that by checking for continuity between the earth terminal of the IEC socket and each of the panels in turn (remove some of the powder coating from an inside surface of each panel to make these checks, if necessary).**

Similarly, check that the heatsinks are earthed to the chassis and that all external screw heads are earthed.

5) Use a multimeter to confirm that the output transistors (Q12 and Q14) are correctly isolated from the heatsink of each power amplifier module.

Testing and adjustment

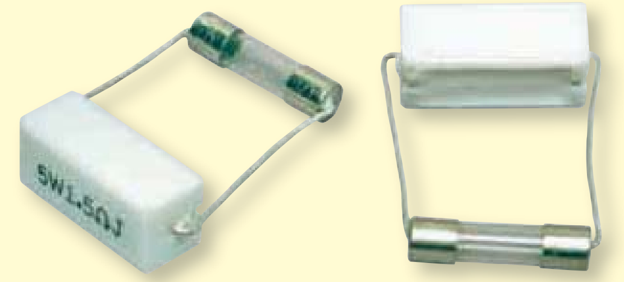
There are three basic procedures to go through here. First, you have to check that the power supply module is delivering the correct voltages. You then apply power to each power amplifier module in turn and adjust its quiescent current. Finally, you power up the preamplifier and loudspeaker protector modules and check their operation. Here's the procedure:

STEP 1: disconnect all nine spade connectors from the +22V, 0V, –22V terminals at the output end of the power supply module.

STEP 2: disconnect the loudspeaker leads from the power amplifier modules.

STEP 3: connect an IEC mains power cable to the amplifier and use a

Adjusting the quiescent current through the power amplifiers



The quiescent current flowing in the output stage of each power amplifier is initially adjusted by installing 1.5Ω 5W resistors in place of the fuses. The voltage across one resistor is then monitored and trimpot VR1 adjusted for a reading of 1.68V – equivalent to a quiescent current of 1.12A.

The easiest way to connect the resistors is to 'blow' the fuse wires in a couple of spare M205 fuses, then drill holes in the end caps and solder the resistors in place as shown. The original fuses can then be removed and the 'modified' fuses clipped into place – see photos.

multimeter to confirm continuity between the earth pin of the plug and the chassis earth. That done, plug the cord into a mains socket and switch on.

Warning: don't go poking around the rear of the IEC socket with power applied. The metal strap that runs from the Live terminal to one end of the fuse carries 230V AC.

STEP 4: check the unregulated ±22V rails at the output of the power supply module. These rails should both be measured with respect to the 0V terminal and should be a little high at around ±24V (since they are unloaded).

If the meter reads 0V, switch off immediately and recheck the connections to BR1.

STEP 5: switch off and connect the supply leads (+22V, 0V, –22V) for the righthand power amplifier to the power supply module.

STEP 6: remove the two fuses from the righthand power amplifier and install 1.5Ω 5W resistors in their place – ie, one in series with the +22V rail and one in series with the –22V rail.

The best way to do this is to solder these resistors across a couple of spare M205 fuses, after first destroying the internal fuse wires. First, drill a hole in each end cap, breaking the fuse wire in the process. The resistor leads can then be bent to shape, fed through the end caps and soldered (see photos).

The modified fuses with their resistors are now plugged into the fuseholders. These 1.5Ω resistors protect the output transistors by limiting the current through them if there is a fault, eg, if the V_{BE} multiplier circuitry (Q10) is not functioning correctly.

STEP 7: wind trimpot VR1 on the right channel power amplifier fully anticlockwise, switch on and check that the amplifier's output voltage (ie, between the loudspeaker terminals) is less than ±50mV. If not, check the base-emitter voltage of each transistor in the amplifier; they should all be 0.6V to 0.7V. Check also that the correct transistor is installed at each location and that they are all the right way round.

STEP 8: assuming the output voltage is correct, monitor the voltage across one of the 1.5Ω 5W resistors and wind trimpot VR1 slowly clockwise until the meter reads 1.68V. This is equivalent to a quiescent current of 1.12A.

That done, let the amplifier run for about five minutes or so and then check the voltage again. During this time the amplifier heatsink will become quite warm and the quiescent current will drift slightly. Readjust VR1 to obtain 1.68V again.

STEP 9: switch off, remove the 1.5Ω 5W resistors and install the 3A fuses.

STEP 10: repeat steps 5 to 8 for the left channel power amplifier module.

STEP 11: let the amplifiers run for about 30 minutes (so that the heatsinks get nice and hot), then check the voltage across one of the 0.1Ω 5W resistors in the right channel power amplifier. Adjust trimpot VR1 for a reading of 112mV. Now check the voltage across the other 0.1Ω resistor – these resistors have a tolerance of about 10%, so set VR1 so that the average voltage across them is 112mV.

STEP 12: repeat step 11 for the left channel power amplifier.

STEP 13: switch off and reconnect the preamplifier's +22V, 0V, –22V leads to the power supply module.

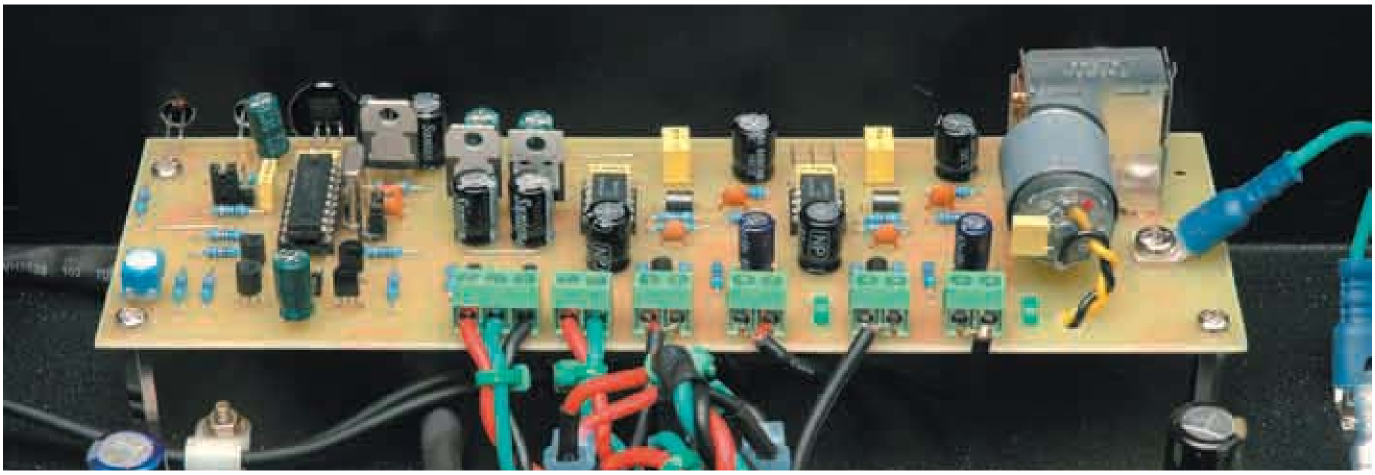
STEP 14: check the preamplifier and remote volume control for correct operation, as described in the Jan '09 issue (skip this step if you've already done this).

STEP 15: check the operation of the loudspeaker protector module if this hasn't already been done.

To do this, apply power and check that the relay turns on after about five to seven seconds. If it does, temporarily short the temperature switch input – the relay should immediately switch off. Similarly, the relay should immediately switch off if you disconnect one of the leads to the AC-Sense input.

Now check that the relay switches off if a DC voltage is applied to the loudspeaker terminals (this simulates an amplifier fault condition). This is done by connecting either a 3V, 6V or 9V battery (either way around) between the LSPKIN+ terminal and the ground terminal of CON1. The relay should immediately switch off.

Repeat this test for the RSPKIN+ terminal, then reverse the battery polarity and do these two test again. The relay should switch off each time the battery is connected (see also pages 26 and 27



This close-up view shows the mounting details for the preamplifier module. Note that it is mounted on three 25mm spacers only – two at the back and one at the front near the power LED. The other end of the board is supported at the front by securing the pot shaft to the front sub-panel (installing a spacer here would stress the pot connections).

Dec '08). Note: you need at least a 3V test battery to bias on the transistors in the DC detection circuit.

STEP 16: switch off and reconnect the loudspeaker leads to the power amplifier modules.

Watch the ventilation

That's it, your new 20W Class-A Stereo Amplifier is now ready for action.

Just one final thing – as previously mentioned, the heatsinks get quite hot and the air must be allowed to flow freely through the bottom and top ventilation slots. This means the amplifier must sit out in the open on a hard, level surface. Do not enclose it in a cabinet and do not stack anything on top of it. *EPE*